SCIENCE NEWS

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EDITED BY J. L. CRAMMER

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Editorial

POLITICIANS are pre-occupied just now with the problems of economic recovery after the devastation of a six years' war. One of the greatest of these is the frequency of absenteeism and sudden strikes, and this is a matter on which science, though but infrequently consulted, has something to say. Dr Lloyd Davies provides a brief introduction to the whole field of health in industry, and indicates something of the scientific explanation of absenteeism in the course of his wide review. This issue of *Science News* also ranges widely in other directions: the Northern Lights, the Wind and the Weather generally, under the headings of astronomy and meteorology; the health of domestic animals, and the treatment of human tuberculosis, under biology and medicine; while a report from the Antarctic gives a further impression of modern exploration and scientific work in the field which rounds off the accounts presented in previous issues. As announced previously in No. 10, biochemistry is to get attention each quarter, when some specialist will treat of his own particular subdivision of the science: this time, it is Dr Kendrew, writing on the physics and chemistry of the proteins.

It is worth remarking that of the ten separate articles in this issue, five were not commissioned, but were sent in by their authors as 'free-lance' contributions – and previous issues show the same kind of mixture. This should be an encouragement to people interested in writing popular science articles, particularly to those still hesitant about trying. We noted in 1947 the shortage of authors, and the gaps, also, in Britain in the ranks of the professional scientific journalists, and the position has not changed greatly since. Demand still exceeds supply. This being so, anything in the

slightest degree suitable has a good chance of publication; and as to suitability, a note at the beginning of *Science News* 4 indicated briefly what this means at least for us.

ERRATUM

Figure 7, page 49, in *Science News* 10, purports to be the formula of Chlorophyll, but in fact the wrong figure has been printed. We are getting a new block made, with the correct formula, and this will appear in the next issue.

Aurora Borealis

JAMES PATON

DURING the two or three years immediately following the maximum of the sunspot cycle, the aurora not only occurs more frequently and in its most striking forms, but it also extends to lower latitudes. So, as the peak of the cycle has now been reached (1947), we may reasonably expect in Britain during the next year or so, to witness this phenomenon in all the grandeur of colour and pulsating movement that often characterises its activity when overhead. Unfortunately, even the wan street lighting of these times of austerity is sufficient to prevent the town dweller from appreciating the beauty of a clear starry night, let alone the magnificence of the aurora, a magnificence that far transcends any impression derived from the most graphic description or photograph. It is the countryman who is best placed to observe and so is most familiar with the aurora.

The name *aurora borealis*, meaning northern dawn, was first used by the French philosopher and mathematician, Gassendi, in 1621. It no doubt accurately describes the normal appearance of a display observed in low latitudes, and is the name most commonly used in France and the English-speaking countries. But in more northern countries, the name northern lights or streamers (Scandinavian *Nordlys-Nordljus*) is more appropriate. It was not until the mid eighteenth century that it became well known in Europe that displays similar to aurora borealis occur in the sky at corresponding latitudes of the southern hemisphere, and this southern counterpart of aurora borealis became known as *aurora australis*.

It should be mentioned that the name aurora is sometimes

applied in another connection. On a clear moonless night, you will have noticed that the sky, far from being pitch black, is bright enough to show the outlines of tall buildings silhouetted against it. The sky actually illuminates the ground with an intensity approximately that of a 25 candle power lamp at a distance of 500 yards. This 'light of the night sky' while consisting partly of light from the stars and zodiacal light (scattered sunlight), is mainly composed of light emitted directly by the high atmosphere. It is often called the permanent aurora, to distinguish it from the more spectacular polar aurora.

The earliest recorded accounts of auroræ appear in the famous *Meteorologica* of Aristotle, a remarkable work that supplied the modern name for the science of weather. Later, Pliny tells how the aurora came to be regarded as something supernatural, presaging evil events. It is hardly surprising that, on the rare occasions when particularly bright auroræ have been seen in Mediterranean countries the inhabitants were considerably perturbed. In 1585, thousands of peasants from the country round Paris, terrified by a great aurora, 'trooped into the city to offer prayers in the Great Church.' In northern countries where it is frequently seen, it holds no terror for the people.

The aurora occurs in a wide variety of forms from the quiet arc, extending across the sky from the western to the eastern horizon in the shape of a complete rainbow, to the complex and often extensive draperies and curtains in continual feverish movement. Sometimes only a few sharply defined rays are visible; at other times there may exist nothing more than a diffuse sky illumination that periodically waxes and wanes in intensity. The predominant colour is usually white, developing to yellow in the parts where the intensity is greatest, but in a brilliant display vivid reds and greens appear. It may appear only for a few moments; occasionally it may continue active from sunset to sunrise. It is impossible to predict the course of a particular display, but the following description (from *Weather*

Vol. 1, No. 1, 1946) of auroral activity observed by the writer at Abernethy, Perthshire on a night in March, 1946 gives the sequence of forms that most frequently occurs (see Plate 29).

'On the almost cloudless night of Saturday, March 23 last, there appeared about 10 p.m. on the northern horizon, the bright glow so aptly named aurora borealis, the northern dawn. This is not an uncommon occurrence in the northern parts of these islands and it excited little interest until an hour later, when the glow kindled rapidly into brilliance and, ascending slowly from the horizon, assumed the shape of a huge arc with Cassiopeia apparently resting on its summit. By contrast, the region between the horizon and the brilliant lower border of the arc appeared utterly black. But the absolute intensity of the light of the broad arc could hardly be as great as the contrast suggested, for Algol shone through it with little apparent reduction in brightness. Indeed, while it was possible to read the numbers painted on the photographic slides, details of the landscape, which would show clearly by moonlight, were just recognisable in the light of this bright aurora.

'Suddenly, the arc, which had remained perfectly quiet and regular during its ascent and development, broke into feverish activity along its whole length, dividing here into bundles of short rays, and there into diffuse pulsating patches of light. Tinges of red and green sparkled to enhance the yellow-white, which so far had been the prevailing colour. The rays were leaping upwards, one bundle subsiding as an adjacent one darted ahead, and eventually the northern half of the sky was filled with streamers. At this stage, the aurora belied that name and conformed rather to its Shetland title "the Merry Dancers."

'The rays danced overhead into the northern half of the sky, apparently converging to the magnetic zenith, i.e., the spot in the heavens to which the south pole of a freely suspended magnetic dip needle would point (in this case 20°S of the vertical zenith). The play of the rays in the corona round this point reveals that the magnetic field

of the earth exerts a directive influence on the agent responsible for aurora.

'The coronal rays now merged to form what appeared to be a bluish-white vapour, sometimes like "the smoke of the straw which is burned in the country" (*Meteorologica*), at other times remarkably like cirrus clouds. Before long, however, the "vapour" resolved itself into rays, patches of green light waxed and waned in the east and a quite fantastic cloud of brilliant red appeared and remained fixed in the western sky for almost an hour—so unreal that one imagined it to be a reflection of a gigantic fire below the horizon. It was such an illusion which caused fire engines to race towards the horizon in many parts of S.E. Europe during the great display of January 25, 1938 and, much earlier, the soldiers of Tiberius to hasten to assist the inhabitants of Ostia, thought to be ablaze.

'In the most intense phase of the display, waves of light surged up from the horizon to the zenith, fanning weaker rays and patches into brightness as they swept over them, like a breeze blowing over the dying embers of a large bonfire. At 02.30, the display subsided as suddenly as it had developed, leaving only a weak residual illumination in the sky, enlivened by sporadic slight ray activity.'

The resemblance of aurora to cirrus clouds noted in this description (see also Plate 29) is often very striking, as the following extracts from notes of a display on October 1, 1838 by the skilled French observer Bravais show:

'11.45. Is it cirrostratus (cloud) or an arc?
11.57. The arc seen at 11.45 is decidedly cirrostratus.
12.15. The cirrostratus simulates the arc of an aurora.
02.00. These (cirrus clouds) seem to obey the force which directs the aurora.'

The general reader will find excellent general accounts of aurora in Angot's *The Aurora Borealis* (1896) and in *Polar Lights*, privately published (1947) by Cicely M. Botley of Tunbridge Wells.

An analysis of the geographical distribution of aurora in the northern hemisphere was made as long ago as 1881 by Fritz, who reproduced his results by drawing on the map

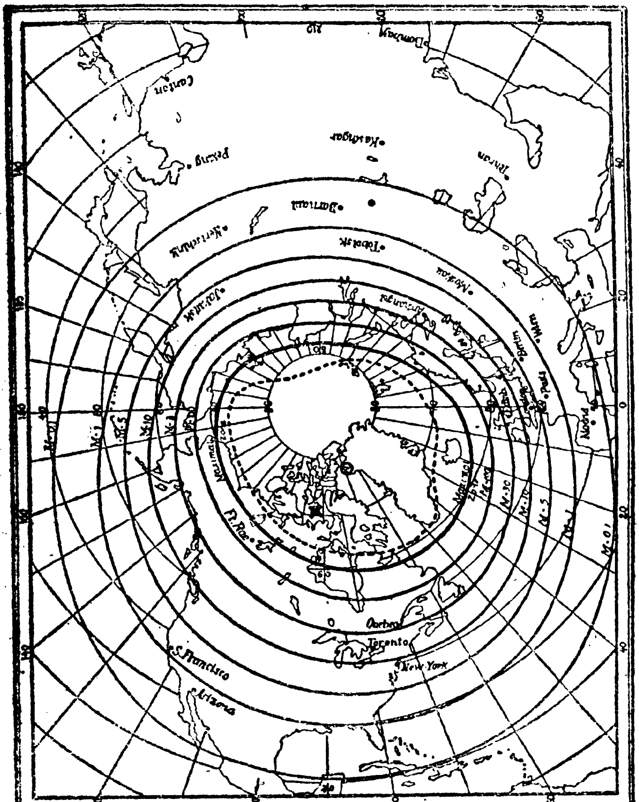

Fig. 1. – The distribution of isochasms, or lines of equal auroral frequency, in the northern hemisphere, according to Fritz (after Chapman and Bartels). Courtesy of the Royal Meteorological Society, from *Weather*, Vol. 1, No. 1.

lines of equal auroral frequency, called by him isochasms (Fig. 1). These lines do not run parallel to lines of geographical latitude but coincide approximately with latitude lines drawn with respect to the pole of homogeneous magnetisation of the earth (The earth's magnetic field does not differ appreciably from that of a uniformly magnetised sphere. The field of such a sphere which most closely fits the observed earth's field is found by harmonic analysis to have a north pole at approximately 78.5°N 69°W, i.e. about the N.W. tip of Greenland, the south pole being at 78.5°S 111°E). The map shows that the aurora is observed on the average about seven times per year in London, 25 times in Edinburgh and 100 times in Lerwick. In the Mediterranean area, it is seen about once in ten years. The frequency of occurrence does not continue to increase with increasing latitude. The maximum frequency occurs in a zone which stretches round the earth from north of North Cape, passing between the Faeroes and Iceland, south of the southern tip of Greenland, across northern Canada and running parallel and to the north of the northern coasts of Eurasia. Both north and south of this line there is a rapid decrease in frequency. The hatched line represents the region where aurora is seen equally frequently to the north and south. Using observations made during the International Polar Years 1882-3 and 1932-3, when the nations co-operated in making meteorological and magnetic observations in high latitudes, Vestine (1944) has completed the Fritz chart by drawing the isochasms on the poleward side of the maximal zone.

Attempts have been made to construct a chart of the geographical distribution of aurora australis, but the paucity of observations detracts from its value, though there is little doubt that the lines of equal frequency are roughly symmetrical about the southern axis pole at 78.5°S, 111°E. For example, aurora is seen much *less* frequently in South America than at the same geographical latitude in Australia.

Measurement of the Height of Aurora

The method used to determine the height and position of an aurora is similar to that used by surveyors to find the height of a mountain. If the angle of elevation and the azimuth of the mountain top are known for each of two observing stations at the end of a measured base line, the height and position of the summit may be calculated by simple trigonometry. The greater the size of the angle between the lines of sight from the two stations to the summit (this angle is known as the parallax), the greater the accuracy of the calculation. But it is a different matter when we apply the method to an aurora in continual movement. Observations must be made of the *same point* of the aurora simultaneously at the two stations. Clearly, accurate results can be expected only by replacing the surveyor's theodolites by cameras and using the calculated position of the star background of simultaneous photographs in place of the theodolite scales. If the time at which the exposure is made is known, the position of the stars with respect to the observing stations may be calculated from star almanacs. This method was first developed by Professor Carl Störmer of Oslo, whose network of stations in Norway with base lines of length between 20 and 400 kilometres has been operating for over thirty years.

By arranging that the objective (Astro f/1.5, focal distance 5 cm.) slides into six positions relative to the plate, the auroral camera takes six pictures on each 9 x 12 cm. plate. It may be directed to any point in the sky and then clamped before making an exposure (Plate 28). The photographers are in continuous communication by line telephone using breast-plate microphones and headphones, so that the hands are left free to manipulate the camera. (The interference that often accompanies aurora renders radiocommunication unreliable in this work.) A hinged metal flap that falls over and covers the front of the objective is used in making exposures, so that the camera may be easily operated wearing

gloves. An observer at one station directs photography, saying, for example, 'Direct on Polaris.' When the photographer at each station has signified that all is ready, the directing observer says 'On' and, after an interval depending on the intensity of the feature being photographed, 'Off.' In this way, photographs are taken simultaneously at all stations. A recorder, seated comfortably indoors wearing telephone headgear, hears these instructions as they are uttered. Observing an accurate chronometer set to G.M.T., he records the times of making and ending exposures to the nearest second, the reference star and any remarks made by the photographers on the auroral forms, intensity and so on. With the fast plates now available, exposure times range from 2 to 10 seconds, orthochromatic plates being used, except in the case of red aurora, for which panchromatic plates are employed. Corresponding plates from the various stations are developed in the same tank.

Measurement of the plates

Using identical projectors the corresponding photographs from two stations are projected simultaneously side by side on art paper, the magnification being adjusted so that 1 centimetre corresponds to 1° at the optical centre. The outlines of the aurora common to both pictures are then drawn in pencil and the star background marked and identified. The declination and right ascension of three stars suitably disposed with respect to the auroral features to be measured are obtained from a star almanac. Knowing the time at which the exposure was made, the hour angle (the angle between the meridian through the star and the main station observer's meridian) is found for each of the three stars from their right ascensions. After a somewhat lengthy and involved process, the same measurements as are obtained by the surveyor directly from his theodolites are determined, namely the azimuth and elevation and the parallax, so allowing the calculation of the height and position of the aurora.

The analysis of the great mass of observations accumulated by Störmer from the photographs obtained by his network of stations is now proceeding. The lower border of a curtain has been found occasionally to be as low as 80 kilometres, while rays in the sunlit part of the atmosphere may extend to heights of 800-1,000 kilometres. Similar work is being undertaken in Britain during the current period of sunspot maximum, stations being situated at

		Latitude	*Longitude W*
A	Abernethy	56° 20′ 1″	3° 18′ 38″
B	Blairgowrie	56° 34′ 50″	3° 20′ 36″
C	Newton Stewart	54° 57′ 37″	4° 29′ 6″
D	Bridlington	54° 5′ 10″	0° 12′ 43″

The lengths of the base lines in kilometres are AB=27.6, AC=169.8, BC=194.1, AD=318.4, BD=341.2, and CD=292.8 km. Each station is manned by voluntary observers, Mr McKellican, the Divisional Road Surveyor for East Perthshire at Blairgowrie; Mr Geddie, the rector and members of the staff of his science department (Miss Morrison, Mr McFadyen and Mr Wilson) of the Douglas Ewart High School at Newton Stewart; and at Bridlington School, Mr Reeve, the retired science master, and Mr Greenhalgh. Each station is supplied with boxes of loaded and numbered dark slides, ready for use. After exposure, the slides are returned for development and measurement of the plates at the Physical Laboratory, Edinburgh University. Even if no aurora occurs, the slides are reloaded with fresh plates every three months.

Using these very long base lines, the displacement of the aurora against the star background may be so great that, though the cameras at the stations are directed towards the same stars, the pictures will not include the same parts of the aurora. In this case, the cameras are directed at corresponding parts of the aurora, not necessarily at the same stars, and in measurement a different set of three stars must be used for each picture.

Watch is kept each evening at the main station till 11 p.m. If aurora develops at a later hour, the night observer at a nearby station of the Meteorological Office warns the main station.* Information of sunspot activity, the significance of which is explained later, is obtained from the Royal Observatory, Greenwich.

If an aurora is deemed suitable for photography, the night supervisor at Perth Telephone Exchange is asked to ring the stations with a warning to prepare the cameras and photography commences as soon as each has reported that all is ready. Invaluable assistance is given by the staff of G.P.O. telephones, in particular by the night supervisors of Perth Exchange (through which the stations are linked) in securing good lines. The telephone speaking clock is used at intervals to check the stop-watch.

A scheme for the photography of quiet arcs has been arranged in collaboration with the Scandinavian network. When such an arc appears, six exposures (one plate) lasting 20 seconds each are made commencing at the exact hour G.M.T., 15 minutes after the hour, 30 minutes after and so on, according to the following arrangement. The first exposure is made on the W. end of the arc beginning at, say 20h. 00m., the second on the highest point of the arc at 20h. 01m., and the third on the E. end at 20h. 02m. The fourth, fifth and sixth exposures are made in the reverse direction beginning at 20h. 03m., 20h. 04m. and 20h. 05m.

*An amusing and at the same time somewhat tantalising incident that happened some time ago is worth recounting. An aurora having developed in the small hours, a night observer, apparently reluctant to telephone directly to the main station, delegated the task to the telephone night operator by sending the information by telegram addressed to the main station telephone number and worded 'Aurora at forty-five,' meaning that auroral activity extended to 45° above the horizon. It was not until the main station observer was at breakfast that the telegram was read to him from the exchange. Asked why it had not been transmitted as soon as received, the operator explained that, being sure this was a piece of racing information, he had, with the kindest of intentions, refrained from telephoning until a more respectable hour!

respectively. If the arc still remains, another series would commence at 20h. 15m. If simultaneous photography has been possible in Scandinavia, the geographical position of the arc may be plotted from the Atlantic to Russia, information likely to be of value to the workers on the theory of aurora. The British measurements may also reveal if there is a variation of auroral height with geomagnetic latitude (latitude referred to the axis poles, not to the geographical poles), a variation already suggested by Störmer's own results from northern Norway and those of the British Polar Year Expedition 1932-3 under Stagg.

Observations of the position of sharply defined auroral features with reference to the star background are always of value. Star charts on which sketches may be drawn and instructions as to their use may be obtained from the writer at the Department of Natural Philosophy, The University, Edinburgh. Drawings of this kind from a wide area would provide a useful supplement to the photographic work.

Other applications of the network: Stratospheric clouds and meteors

Using precisely the same method, the network of stations may be employed to determine the positions of two kinds of clouds that occasionally appear in the night sky. *Luminous night clouds*, appearing in middle latitudes in summer, are thought to consist of meteoric or volcanic dust and have been found to occur at heights of just over 80 kilometres. By taking photographs at regular intervals, the rate of drift of the clouds may be calculated, thus yielding information about air movement in the stratosphere. The luminous clouds travel with speeds usually between 40 and 90 metres per second (90 – 200 m.p.h.), but a reliable observer claims to have measured speeds of the order of 600 m.p.h.! *Mother of pearl clouds*, so called because of their lovely iridescent colours, appear most frequently in winter at heights of about 16 miles. (Ordinary clouds never appear above heights of 8 miles). Because of their great

height, each of these kinds of cloud remains visible long after the sun has set at ground level.

The train of dust left by a meteor may remain visible for as long as an hour during periods just before sunrise or after sunset so that it shows up bright by reflected sunlight against the darker sky. Since it extends through a considerable height and drifts with the air flow within the stratosphere, it soon loses its straight-line form and may later appear like the coils of a giant snake in the sky. Measurement of successive simultaneous photographs of the meteor train therefore gives complete information of air movement over a great range of heights in the stratosphere. Störmer's network successfully photographed a meteor train that appeared between the Aaland Isles and Abo in Finland at 04.00 G.M.T. on October 10, 1946. Another was visible in Southern England on the night of August 12, 1948.

The meteor, or shooting star, is visible by the luminosity of the incandescent vapour left in its trail as a result of the intense heating by friction with the air. (*Science News* 5, p. 32.) It eventually is evaporated and reduced to ashes. This luminosity is short-lived and, of course, ends with the disappearance of the meteor. (Distinguish this from the much rarer occurrence, the meteor train just considered, where the track of residual dust is seen by reflected sunlight.) The duration of visibility of the shooting star is so short that, despite the frequency of their occurrence, the track has appeared on only one of Störmer's many thousands of pairs of auroral photographs. When this does occur, the heights of appearance and disappearance of the meteoric luminosity, and the direction of its track in space may be accurately determined. But, while the probability of securing simultaneous photographs of shooting stars is normally small, it is sufficiently high during periods of showers to justify the use of the auroral stations in making a continuous series of successive short exposures on a selected part of the sky.

A discovery which may lead to a simplification of the

method of measuring auroral height was made by Lovell and his collaborators in Manchester on the night of August, 15–16, 1947, when they were engaged on their study of meteoric ionisation by radar methods. It happened that, on that night, extensive auroral activity developed. Noticing unusual intermittent radio echoes, the observers found that they were apparently associated with the appearance of a blue-grey auroral cloud at a ray tip at 480 kilometres. Although the display remained active for some time, these were the only unusual echoes observed. It may well be that radar methods may be applicable to height measurement of particular types of aurora, but the exact interpretation of the results must await further observation. (See *Science News* 6, p. 139.)

The Spectrum of the Aurora

The light of the more familiar optical phenomena of the atmosphere like rainbows and haloes is partially polarised, i.e. there is a preponderance of vibrations in one particular direction. Polarisation is produced in the processes of reflection and refraction. Its presence in rainbows and haloes indicates that their light originates in the sun and is merely directed to the observer by reflection or refraction in raindrops or ice crystals. Auroral light shows no such polarisation. It is emitted directly by the atmosphere. The spectroscope reveals both lines and bands (sets of lines so close together that the system may appear continuous) in the spectrum of auroral light. The lines are the result of changes within atoms, the bands of changes within molecules. By comparing the auroral spectrum with spectra of known gases produced in the laboratory, the composition of the atmosphere at the site of auroral luminosity may be ascertained. But the process has proved exceedingly difficult and the identification of some of the bands is still in doubt, and even the lines have presented considerable difficulty.

It was a long time before the well-known green line, wavelength 5577 Å (1 Å$=10^{-8}$ cm.), was shown to be due to

what is called 'a forbidden transition' in the oxygen atom, a change that occurs in the laboratory only under special conditions of electrical excitation. At the end of this change, the atom having emitted green light is still in an excited (called 'metastable') state, i.e. it is still capable of undergoing further change and so of further emission of light before finally reaching its 'ground state,' the state when its capability of light emission has been exhausted. The light emitted during this final change is red in colour.

Further interesting discoveries followed. It was found on directing the spectrograph at different points along the path of a particular auroral ray, that the intensity of the red light increased relative to that of the green light on passing up the ray. The explanation lies in the following facts. If an atom in the metastable state collides with another atom or molecule, it passes to the ground state without emission of the red light that would have resulted had it been left to make the change in its own time, free from collision. When a collision does take place, the energy that would have gone in light emission is shared between the colliding particles as energy of increased motion. Now, because the density of the atmosphere decreases progressively with height, the number of collisions among atoms and molecules in the rarer air of high levels is reduced. The oxygen atoms at the greater heights suffer many fewer collisions and so proportionately more of them are left free to proceed to their ground state in their own way with the emission of red light. So, the higher the level of the aurora, the greater is the intensity of the red light relative to the green. Red colour in aurora therefore usually signifies great height. It is for this reason, too, that the aurora visible in exceptionally low latitudes is usually red in colour, for the lower portions of the display are below the horizon. It is not quite certain whether lines from atomic nitrogen similar to these forbidden lines of atomic oxygen are also present.

The auroral light most important from the point of view of photography occurs in violet and blue bands, identified

as emission from singly ionised (one electron removed) nitrogen molecules. Recent work indicates that hydrogen and helium may also be present in the high atmosphere.

While spectroscopic examination reveals these differences in composition of the high atmosphere from that at the earth's surface, it also allows a rough estimate of air temperature at auroral levels to be made, either by determining the relative intensities of the lines in a particular band or by observing the width of a particular line. Each of these changes with change in temperature of the emitting source in a known manner. For example, at high temperatures, the more vigorous movement of the atoms and molecules of a gas causes slight alterations, by Döppler effect, in the wave length for a particular line, a slight decrease for some atoms and an increase for others, depending on the speed and direction of movement. The line therefore widens with increase in temperature. By the first method, Vegard estimates that the air temperature between 110 and 150 kilometres altitude is of the order of –30°F, while he finds that the width of the green oxygen line is constant, indicating constant temperatures over the height range 100-300 kilometres (–30°F= –34.4°C).

While spectroscopic examination of the light of the night sky, the permanent aurora, shows that it is similar in many respects to that of the polar aurora, it also reveals the surprising result that sodium in the atomic form is a constituent of the high atmosphere.

The possibility of producing aurora artificially has been examined theoretically. Such investigation shows that this may be feasible in regions where the earth's field is nearly vertical. Beams of radio waves of a certain frequency and type (circularly polarised gyro waves) projected vertically may excite the high atmosphere to emit visible light. A patent has been taken out for the use of such artificially stimulated aurora for city and roadway illumination. Even if the project were found practicable, it would only be effective, of course, on a cloudless night!

Can the Aurora be heard?

Many reliable observers claim to have heard the sound of aurora, describing it as 'swishing,' 'hissing' and 'rustling,' some even reporting having seen green auroral light against a background of hills. One account describes a curtain, so low that observers 'unconsciously dodged to avoid it,' one going so far as to say that he had to lower his head and put up his hands as if to ward off a blow! During the operation of the Scandinavian network on a great display in 1935, one of the photographers informed Professor Störmer over the telephone that he was convinced that he was hearing sounds accompanying the aurora. The following is an extract from the report he later sent to Professor Störmer. 'During the wonderful display of the great Corona when the whole sky was full of rays, my assistant and I heard a remarkable sound which lasted about ten minutes. Its intensity followed that of the aurora and it seemed to be associated with the white rays. My assistant called my attention to it first and I heard it when I took the telephone from my ears. With the 'phones on my ears, I heard nothing, so it could not have come from the telephone. The noise is difficult to describe. It was similar to that of burning dry grass and twigs. In the mountains, where our station is situated, there is only a pine forest which stretches under us for miles. It was quite still in the mountains; no sound of wind, waterfalls, telegraph lines or motor cars. So my assistant and I are quite sure we heard it and that it was no illusion.' It is difficult to explain these sounds in the light of the information yielded by the height measurement, that aurora seldom comes below 100 kilometres (60 miles). When observing an intensely active auroral curtain with its remarkable variations in form and luminosity, it is often difficult not to associate with it sounds of local origin, involuntarily imagined to be in phase with the movements of the curtain. So, unless some kind of auroral influence occurs at heights lower than those measured, we must assume that the sound

heard has no connection with the display. It has been suggested that the sound may arise in cold regions from ice crystals in the breath of the observer or, more generally, from the chance occurrence simultaneously with the aurora of the electrical conditions in the atmosphere that cause the hissing associated with the brush discharge of St Elmo's Fire.

It is just as difficult to explain reports of the appearance of auroral light near the ground. The physical conditions necessary for the emission of light from the atmosphere do not obtain at low levels and it is more than likely that the auroral light observed has been reflected from mist.

The Cause of the Aurora

The observational facts on which any theory of auroræ must be based, in addition to those already stated, are these.

The aurora is generally accompanied by magnetically disturbed conditions, i.e., by fluctuations in the earth's magnetic field. In the most severe of such disturbances, the great magnetic storm, when electric currents of the order of one million amperes flow in the auroral zones, the declination for example may change by as much as 2°. Irregular magnetic fluctuations are most marked in the auroral zones.

Frequency curves of auroræ and sunspots are similar, each showing an eleven-year cycle, the maxima for auroræ lagging behind those for sunspots by about two years.

A great aurora is almost invariably associated with a large sunspot and usually occurs about a day after the sunspot has crossed the sun's central meridian.

There is a tendency for aurora to recur at intervals of 27 days.

Now examine these facts in the light of the known properties and behaviour of sunspots, for undoubtedly the process leading to the development of both the aurora and magnetic storms has its origin in the sun.

Sunspots appear to the observer as black regions against

the brilliance of the solar disk. They are often easily visible to the naked eye and are best observed through dark glass to reduce the glare. The area of the sun in the vicinity of the spot is intensely active and is the source of both corpuscular and ultra-violet light emission. While some spots are short lived, a few of the larger spots persist for a period longer than that taken by the sun to make one complete revolution (as observed from the earth, this is 27 days). They therefore reappear at the edge of the disk about 27 days after their first appearance there. Spots appear in the central region of the sun between 30° north and south of its equator. Starting from the minimum at the beginning of the cycle, when the spots occur at the outer limits of the region, the mean position of appearance of the spots moves towards the equator, so that towards the end of the cycle, i.e., at the succeeding minimum, eleven years later, they are near to the equator. By this time, the first spots of the next cycle have already made their appearance about 30° north and south of the equator.

At times, a brilliant flare or eruption may suddenly be seen by specially designed equipment to burst out near a sunspot, accompanied by a great increase in the emission of ultra-violet light. The flare lasts on the average about half an hour and is almost invariably associated with sunspots. Coinciding with the appearance of the flare, and no doubt due to the intense ionisation of the radio wave-reflecting layers of the atmosphere produced by the increased emission of ultra-violet light, there occurs over the sunlit part of the earth serious interference with radio transmission, a 'catastrophic fade-out.' About a day after the appearance of an unusually intense flare, there follows a great magnetic storm and aurora, accompanied by further, now world-wide but less drastic, radio interference. These are almost certainly caused by a stream of corpuscles, whose properties are presently to be examined. Note that the first effect is almost instantaneous with the appearance of the flare, the second lags behind the time of emission of the corpuscles from

the sun by the period taken for their passage from sun to earth.

There is yet another accompaniment of the aurora and the magnetic field fluctuations of the magnetic storm. Electric currents induced in the earth's crust may locally be sufficiently great to interfere seriously with line telephone communication.

Returning to the question of the solar agent responsible for the aurora, we see that it may take the form either of a stream of fast moving corpuscles or a burst of ultra-violet light.

The 'ultra-violet' theory

According to this theory, there exists, at all times, an extension of the atmosphere to a height of 40,000 kilometres caused by the propulsion outwards of neutral molecules from the normal fringe of the atmosphere, through collision with molecules energised by absorption of solar ultra-violet light. In normal conditions, these electrically neutral high-level molecules simply fall back to their original level, but, when a solar flare occurs, they are all ionised by the intense ultra-violet light, so that the resulting ions and electrons, being electrically charged, now move under the influence of the earth's field along the lines of force that traverse the region where they are formed. Now the lines of force that descend into the auroral zones cross the equator at a height of about 40,000 kilometres, so the ions and electrons end their journey in the higher pressures of low levels in this zone by recombining and emitting light, the light of the aurora.

But, in the intense ultra-violet light, not only the molecules at the highest levels are ionised. Those molecules proceeding upwards from the normal atmosphere on the journey to high levels, a journey calculated to take about three hours, are ionised long before they reach the summit. They therefore abruptly change their direction of motion on ionisation, to follow lines of magnetic force that enter the normal atmosphere in latitudes lower than those reached by

molecules starting from high levels. In this way the equatorwards movement of the auroral zone during magnetic storms is explained.

The main objections to the theory are that it cannot account for the production of a sufficiently large number of particles, and that the velocity of re-entry of the particles into the atmosphere is far too small (about 10 km. per sec.) to explain their penetration to auroral levels. Chapman has also pointed out that the rapidly varying form and the thinness of auroral curtains could hardly be produced in a process of this nature.

Corpuscular Theories

The geometry of corpuscular streams emitted continuously from a small region of the sun has been examined by Chapman. Assuming that the particles issue radially, at a speed

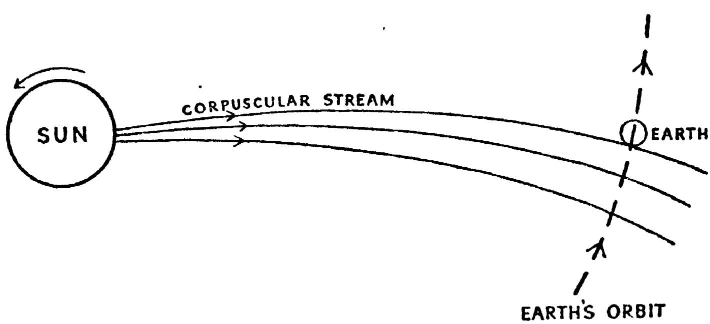

Fig. 2. – The stream of corpuscles from the sun (after Chapman and Bartels, *Geomagnetism*, O.U.P.).

large compared with their initial transverse motion (motion with the sun), the stream will curve backwards from the emitting source as the latter rotates with the sun, each particle in the stream retaining its radial motion. Consequently, the stream will assume the form of a curved cylinder of continuously increasing diameter (because the radii passing

through the boundaries of the emitting area diverge), and will resemble the jet of water from a hose, the nozzle of which is kept rotating (Fig. 2). Ignoring the deviation in the earth's field, the stream will impinge first along the meridian which is moving into shadow, i.e. along that part of the globe where the sun is about to set. It is likely to strike the earth only when it originates near the centre of the disk, i.e. at the central meridian. It has been noted that the aurora often occurs some 24 hours or so after the central meridian passage of the spot or the appearance of a flare, so that it is reasonable to assume that the particles take this period of time to travel from sun to earth. This allows a rough calculation of the speed of the particles, which is found to be 1,600 kilometres per second (60,000 miles per minute). Milne has shown that speeds of this order of magnitude may be produced in certain particles (calcium ions for example) leaving the sun under the influence of radiation pressure. Chapman pointed out that the presence during a magnetic storm of such a stream of fast-moving particles might be revealed by an examination of the solar spectrum at this time. For, as a consequence of Döppler effect due to the great speed of the particles, there would be a displacement of absorption by as much as 20Å to the ultra-violet side of the principal lines, the intensity being proportional to the concentration of absorbing ions in the stream. Confirmation of this prediction by the examination of the absorption lines of ionised calcium has come from Mount Wilson (Richardson, 1944) and from Cambridge (Brück and Ruttlant, 1946).

A likely explanation of the observed lag in the time of greatest frequency of occurrence of aurora a year or so behind the period of maximum sunspot activity is also provided by this theory. At the sunspot maximum, the spots mainly appear at some distance from the sun's equator, but during the succeeding years, although they decrease in number, they occur in positions nearer to the equator and so more favourably situated for the issuing streams of corpuscles to hit the earth.

The effect of the earth's field on such a stream of charged particles was most beautifully demonstrated experimentally as long ago as 1896 by the Norwegian, Birkeland. He projected a stream of cathode rays (electrons) on a small spherical electro-magnet (simulating the earth and its magnetic field) and found that the stream 'came down to the little earth model in inclined striated wedges of light, striking the surface of the model to produce two narrow luminous bands, one near each pole'. It was seeing this remarkable experiment that first led Carl Störmer to calculate mathematically the path pursued by a single particle on entering the earth's field. He showed that when the initial trajectories lie within a cone of small solid angle, the particles which reach the earth are confined within narrow belts in the arctic and antarctic auroral zones, their paths almost coinciding with the lines of the earth's magnetic field.

While the theory explains a number auroral forms in quite a remarkable way, and has an important application in cosmic ray theory, there are difficulties. A stream of particles carrying charges all of the same sign would soon disperse under the action of electrostatic repulsion, the perturbing influence of which must be appreciable when the 'single' particle is part of a stream of similar particles. The stream can remain coherent during its passage from sun to earth only if it is electrically neutral or the density of the particles composing it is very small. If it consists initially of the ions that Milne had shown capable of acquiring the necessary velocities under radiation pressure, then, in passing out of the sun, electrons would be dragged into it. In this way, the stream may become electrically neutral.

The effect of the earth's field on a neutral stream of this kind has been examined by Chapman and Ferraro, who successfully explained certain features of magnetic storms and demonstrated, in a general way, that the particles in the stream which are directed towards, or nearly towards, the earth, are likely to converge on the earth at the poles. The various auroral forms and their rapid changes in intensity

may be attributed to variations in the constitution, extent and speed of the corpuscular stream. In particular, however, one serious difficulty, that of explaining how particles even with speeds of the order of 1,000 km. per second can penetrate to the levels of observed auroral luminosity, remains unresolved.

Alfvén in a theory published in 1939 offers explanations of the main phase of a magnetic storm, of auroral forms and of the process whereby the particles acquire their outward velocities from the sun. This theory, though also based on a neutral ionised stream of particles, is otherwise quite different from that just described. The stream originates with the emission of high energy electrons and ions from a limited region of the sun's surface. Initially, they are assumed to move outwards in spirals round the sun's lines of magnetic force, the electrons and ions separating as the field decreases outwards. This separation causes the development of charges of opposite sign on opposite surfaces of the stream and so of an electric field across the stream. It is the combined action of this electric field and the sun's magnetic field that is assumed to generate the required velocity in the charges to carry them away from the sun. Alfvén calculates the complicated paths pursued by the two sets of charges in the earth's field and shows that they eventually flow together along the auroral zone. The aurora is regarded as a gaseous discharge occurring in the electric field of space charges of opposite sign associated with the streams. The theory has been criticised on the ground that electrostatic fields, resulting from the distribution of space and surface charge associated with the calculated paths of the particles, would so alter their motions as to destroy any apparent success of the theory.

So, the explanations of the origin and nature of magnetic storms and auroræ present the solar and geophysicist with problems of the utmost complexity, and it would seem that, lacking further information, any theory must remain, in some part, highly speculative and therefore very uncertain.

The Moon and the Weather

An Exercise in Scientific Method for Non-Scientists

K. G. COLLIER

THE most difficult, and possibly the most important, lesson for the non-scientist to learn about science is an appreciation of scientific method. The schoolboy who specializes in science gets a thorough grounding in method in his physics and chemistry; but the layman is not usually interested in pursuing a detailed course of this kind. Besides, the main value of any understanding he may gain will lie in his new appreciation of the potentialities of scientific method in running a modern society, and of the limitations from which it suffers in dealing with human problems.

What is needed therefore is a series of problems of intrinsic interest to the layman, in the solution of which he can practise the basic scientific techniques. These can be summarized under three headings:

(1) Analysis of the problem and definition of its ideas;
(2) Measurement of the data;
(3) Statistical calculation of the results.

It is not easy to find suitable problems, and the purpose of this article is to show how the legendary association of moon and weather changes can be used for a lesson in scientific method. Many people believe that the moon influences the weather, and my experience suggests that a class of non-scientists, whether W.E.A. students or the VI Form of a Grammar School, will readily take up the scientist's challenge to this superstition.

The first step is to obtain weather records for the locality over a period of a few years, and almanacks or diaries that give the phases of the moon for this period. There should be

no difficulty in this, for many schools and town councils keep full records of the weather.

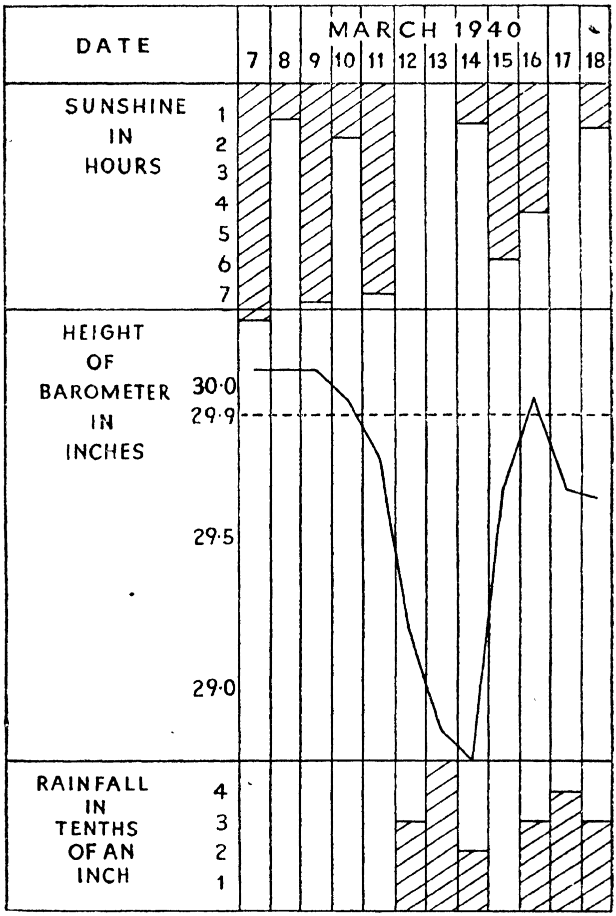

Fig. 3. – Change to wet spell on March 11.

The next step is to analyse the question. How is the moon supposed to affect the weather? A *change* of weather

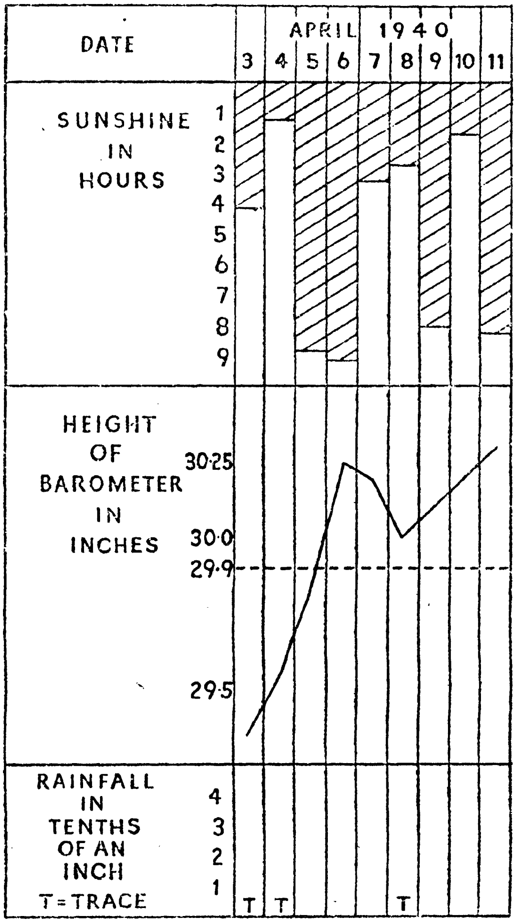

Fig. 4. – Slightly doubtful case, counted as change to fine spell on April 5.

is said to be associated with a *change* of moon. What new phase of moon is to be counted: new moon, full moon,

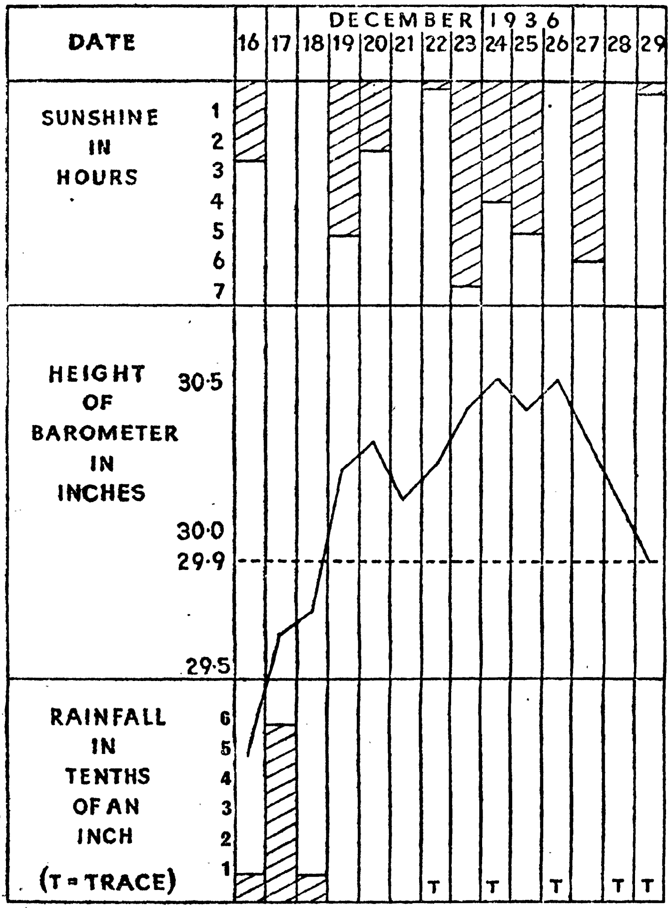

Fig. 5. – Doubtful case, not allowed as a change.

first or last quarter? How are we to define a change of weather? – if we inspect a few months' weather charts we see that the weather changes all the time.

After some discussion my own class – the non-scientists in the VI Form of a Public School – decided that to them a change in the weather meant a break into a fine or wet spell lasting at least three days. They defined a fine spell as one in which a high barometer (above 29.9 inches) was accompanied by long periods of sunshine (8 hours April-September, 5 hours October-March) on at least half the days in the period. A wet spell was defined as one in which the barometer stood below 29.9 inches and rain fell on at least half the days in the period. All other weather was to be ignored. For a change of moon we decided to count the day of a new or full moon, plus one day either side. These criteria may strike the expert as arbitrary; and in fact they are somewhat arbitrary; but the mere realization of the need for definition, and the discussion of the limits to be set, constitute the first of the techniques we listed and a most valuable lesson in the scientific approach.

The next stage is to go through the weather records systematically, enumerating the changes that satisfy our definition. Shortage of time with my own class limited our investigation to the two periods from January, 1935 to December, 1936 and January, 1939 to May, 1940 inclusive. During these 41 months there were 57 weather changes in our area. In 10 cases the break coincided with a change of moon. The layman's immediate reactions were two: (*a*) the theory was disproved; but (*b*) if we had stretched our definition of a change of moon by one more day, we might have proved the connection: a good many changes of weather only just missed a change of moon. This is where the statistical calculations come in.

The average number of weather changes per month was 1.4 – say $1\frac{1}{2}$ at a first approximation. This means, if we take a month as 30 days, one change in 20 days. The chances therefore are 1 in 20 that any one day will experience a

weather change; or, if you like, the odds against a change occurring on any chosen day are 19 to 1. The moon changes twice in 28 days, and therefore the chances of its changing on any particular day are 1 in 14. But we decided to count one day either side of the date given in the diary; and therefore there are three days at each new phase to be allowed for. This means a total of 6 days in 28, or – roughly – a chance of 1 in 5 that a moon change will fall on any particular day.

What then are the odds that any one day will see changes of both kinds? The chance of a weather change is 1 in 20: if we go 20 days we are only likely to have one. But on any one of these days there is only one chance in five of our getting a new phase of moon; and therefore if we repeat our 20-day period five times we are only likely to get a coincidence once. The chance of a coincidence is thus 1 in 5 x 20, or 100.

What do we find in our record? There were 10 coincidences in 41 months, or 1,230 days, that is 1 in 123 days. This is not far off the chance expectation, of 1 in 100, and implies that the moon has no influence on the weather.

What is the effect of counting two days instead of one on either side of the moon change? It is instructive to see.

We now have to count five days at each new phase of moon, or 10 altogether in 28. The probability is therefore now 1 in 3, very nearly, that any one day will see a change of moon; and the chance of a coincidence becomes 1 in 3 x 20. When this criterion of a moon-change was used the number of coincidences rose to 20, which gives us 1 in 1,230/20, or roughly 60 days. The observed frequency again matches the chance expectation; and we see that the change of criterion makes no difference to our conclusion.

The exercise is not quite fool-proof. Haste is unwise at any stage, but it may be fatal to the argument if as a result students do not get enough guidance and practice in judging the weather changes on the charts.

I do not think the circumstances demand, or the case

warrants, elaborate statistical analysis. I have assumed that the lecturer will already have introduced the class to the idea of probability, perhaps in terms of coin-tossing experiments, but that he will not have not gone as far as explaining Standard Deviations. If, however, he has broached these latter topics he can present the conclusions in the following, slightly more precise, form.

The observed number of coincidences is 10 in 1,230 days. The chance expectation is 1/100 of 1,230, or 12.3 in 1,230 days. From the usual formula the Standard Deviation of the score is $\sqrt{(n \times p \times q)}$, or $\sqrt{(1230 \times 1/100 \times 99/100)}$, which comes out at 3.5 (p is the probability of a coincidence occurring, q the probability of its not occurring, n the number of days observed). In short, if we made our examination of the 41-months' period a large number of times we would expect two-thirds of the scores to lie within 3.5 of 12.3, i.e. between 8.8 and 15.8. The fact that the observed score lies well within these limits in the instance quoted simply gives us another way of drawing the conclusion of a chance connection between moon and weather changes.

The experiment cannot be called original research in the scientific sense, but from the layman's point of view it contains several of those very elements of research which fascinate and discipline the scientist's mind. I think these facts would justify its inclusion in any course on scientific method for non-scientists.

Occupational Health

DR T. A. LLOYD DAVIES

In times which politicians and other more reliable judges of mankind have forecast will be known as the age of the Common Man, the relationships of the Common Man are lost in the masses. Paradoxically, the need for production during the war, and the economic stringencies of the peace, have concentrated attention upon the importance of human relationships in industry. Science and technology have been rediscovered to be an inadequate basis for the art of living. The appreciation of the insufficiency of material things in the creation of human well-being and happiness may yet prove to be more important than the great technical discoveries of recent years.

As a goal in itself, happiness will never be achieved, but happiness will come from a healthy personality. Health is wholeness. To achieve wholeness, a man must be in harmony with himself, with his fellowmen and with his surroundings. The assumption of social responsibility, which is the sign of adulthood in Western civilisations, means that a man must achieve wholeness within that of the community.

In a country whose economy is based on industry, work must necessarily be a dominating factor in the direction and extent of community effort and interests. This indirect influence of work on the well-being of man may be not less important than the effect of work on health, so that work is to-day the major influence on the health, happiness and well-being of men, women and children in this country. Factory workers, miners, farmers, quarrymen, sailors, shop assistants, railwaymen, transport drivers, housewives and even university professors may all need to have their working conditions supervised if their health is to be maintained.

The life of man should not be shortened or made a burden because of conditions to which he is subject at work. Still less should man be exposed to the risk of *avoidable* injury or disease.

Occupational Mortality

The standardised mortality ratio, which expresses the deaths experienced by occupational groups as a percentage of the deaths which the same groups would have experienced if subject to the death rate of the whole population (of the same sex), provides a means of comparing the mortality of different occupational groups (*Registrar General* 1931). For males, aged 20-65 years, the highest ratios are for tin and copper miners (working underground), 342; sand-blasters, 304; metalliferous workers, 283; kiln and oven men in pottery trade, 157; stevedores, 220; slate miners, 168; glass blowers, 160; inn-keepers, 155; (all males, 100). The occupational groups with the lowest ratios are wireless operators and telegraphists (not sea-going), 63, and agricultural machine workers and foremen, 55.

The widely differing ratios are an index of the hazards to which workmen in the different trades are exposed. With the exception of inn-keepers, the increased mortality in the trades listed above is due to the inhalation of silica dust. In some trades, comparison of the standardised mortality ratios for men and women shows that social conditions associated with the industry may affect the wives of men working in the industry. For example, furnacemen and rollers working in the iron and steel industry have a high ratio for diseases of the respiratory system due to occupational causes, and their wives suffer a high ratio for nephritis, probably due to the harsh social conditions associated with the industry.

Accidents

The risk of accidents and diseases resulting from work, producing an absence of more than three days, in seven major occupational groups is shown in Table 1.

TABLE I

The Occupational Hazards in Seven Major Industries (see *Workmen's Compensation*, 1938. Cmd 6203) (abbreviated from *The Practice of Industrial Medicine*, 1948. T. A. Lloyd Davies, published by J. &. A. Churchill.)

	Factories	Constructional Works	Railways (excluding clerical staff)	Docks	Quarries	Mines	Shipping
Number of persons employed	5,985,493	275,743	379,694	111,655	78,573	796,382	156,706
Fatal accidents	0.12	0.30	0.65	0.66	0.93	1.23	1.82
Non-fatal accidents	32.59	42.37	45.47	76.12	88.99	166.26	44.66
Fatal disease	0.02	0.07	—	—	0.29	0.15	—
Non-fatal disease	0.54	0.38	0.14	0.30	1.31	10.30	0.01
Total	33.26	43.12	46.26	77.16	91.52	177.95	46.50

The enormous cost of accidents at work is seldom realised. In 1938, the last year for which figures are available, £6,765,067 was paid in compensation for 2,498 fatal and 456,725 non-fatal accidents occurring in the above industries. (Workmen's Compensation 1938 Cmd. 6203). This sum does not take into account the disorganisation and loss of production which always follows even the most trivial accidents. During the war, the great increase in accidents occurring in factories was the result of an increase in the number of persons employed, and the increased speed of work often under difficult conditions with improvised plant.

TABLE II

Variation in Accidents in Places subject to Factories Act, 1937. (from *Annual Reports*, Chief Inspector of Factories).

Year	Number of Fatal Accidents	Number of Non-Fatal Accidents	Approx. Accident Rate per 1,000 persons*
1938	944	179,159	29
1942	1,363	313,267	43
1946	826	222,933	34

*Excluding docks, wharves, quays, warehouses and ships.

Accidents occur because a fallible human being is set to work a potentially dangerous machine. Sir Arnold Wilson and Herman Levy (1941) have adeptly modified Swinburne's phrase 'the malice of things' to apply to inanimate objects which persist in behaving as if possessed of human contrariness.

No clear distinction can be drawn between faults of the machine and failure of the human being who works it.

Too much emphasis cannot be given to Sir Thomas Legge's (1934) famous dictum 'If you bring some influence to bear external to the workman (that is, one over which he has no control) you will be successful [in preventing accidents]; and if you cannot, or do not, you will never be wholly successful.'

In other words, the machine must be made safe no matter what the workman may do. The machine, not the workman, must be fenced. To render a machine absolutely safe is not nearly as frequently impossible as those who try to excuse accidents would like to believe, and the comparatively few accidents due to power-driven machinery in factories prove this contention. Nevertheless, a large number of accidents occur every year, due to more obvious failures of the human factor. To reduce accidents due to the handling of goods, to falling bodies, the use of tools or to locomotion, particular attention must be paid to the training of the workman.

TABLE III

Analysis of Accidents occurring in Factories in 1946 (adapted from *Annual Report*, Chief Inspector of Factories, 1946).

	Number	Percentage Distribution
Machinery (moved by mechanical power)	35,676	16.0
Transport (*a*) Railways	2,676	1.2
(*b*) Other	3,393	1.5
Electricity	769	0.3
Explosion and Fires	2,073	0.5
Use of hand tools	21,705	9.7
Struck by falling body	22,403	10.0
Persons falling	27,849	12.5
Stepping on or striking against objects	16,619	7.4
Other	91,596	50.0

Young persons are specially liable to sustain accidents and they need careful training, especially on first starting work. The Factories Act 1937 provides that young persons

must not work dangerous machinery unless under adequate supervision or properly instructed. Old persons whose mental and physical agility is becoming restricted, are more liable to accidents, and if injured take longer to recover than younger persons. With the ageing of the industrial population, means must be found to ease the physical and mental effort of the older workman, so that he may continue, as Sheldon (1948) has shown he may do with benefit to himself and the community, to make his contribution, not the least of which is his experience.

The work of Greenwood and Wood (1919) has shown that a small percentage of persons, distinguishable by their social irresponsibility and often by mental instability, are more likely to sustain accidents than other persons. Such persons are known as accident-prone. Besides sustaining a larger number of accidents than the average, the resultant injuries are likely to be severe. Accident-prone persons should be employed where the risk of injury is minimal.

Occupational Diseases

Besides damage to the body by violence, the term accident in its widest sense includes harm arising from the many physical and chemical agents employed in industry and commerce. Diseases which have their origin at work are known as occupational diseases; some diseases such as silicosis always have an occupational origin but others, for example lead poisoning, though most frequently the result of work, may occasionally be due to non-occupational causes. Because of the very common association of some diseases with particular sorts of work, the Workmen's Compensation Acts established a list of 'scheduled diseases,' and provided that if a disease specified in the 'schedule' arose in a workman engaged in a specified process the disease was presumed, in absence of proof to the contrary, to be due to work. Compensation was payable for any disease resulting from work, but when not included in the schedule, proof of cause was required.

By July 1948, the schedule included forty-three diseases, and the special nature of these diseases has been recognised under the National Insurance Act. A list of 'prescribed diseases' which is substantially the same as the list of 'scheduled diseases', with the omission of dope poisoning, has been created by the National Insurance (Industrial Injuries) (Prescribed Diseases) Regulations, 1948, No. 1371. The same regulations codify and simplify the rules for compensation for silicosis, asbestosis and pneumoconiosis.

Prescribed diseases include such varied conditions as anthrax, lead poisoning, poisoning by African boxwood, cataract in glass workers, 'beat' knee, elbow and wrist in miners, dermatitis and ulceration of the skin.

The great improvement in industrial conditions since the beginning of the century is reflected in the virtual disappearance of some diseases at one time common; for example, in 1900, 1,058 cases (58 fatal) of lead poisoning were reported, but in 1946 this was reduced to only 47 cases (8 fatal). 'Beat' conditions affecting the knees, elbows and wrists of miners, due to repeated minor injuries associated with the cramped posture in which they work, continue to be troublesome and frequent. Nearly 6,000 new cases of 'beat' conditions occurred in 1938 (the last year for which figures are available). In the same year, 1,020 new cases of miner's nystagmus were added to 4,182 cases continued from the previous year. Dermatitis continues to be an increasing problem in all industries (6,166 cases were reported voluntarily to the Factory Department in 1946). Though the introduction of new substances and materials into industry is partly responsible, it should be remembered that dermatitis never arises from a single cause. Contact between the skin and an external irritant merely 'pulls the trigger of an overloaded gun' in a subject in whom inborn metabolic disturbances, inherited dryness or greasiness of the skin, the presence of sepsis, or worry and anxiety, predispose to development of a skin eruption. Besides substances encountered at work, soap, cleansing

agents (such as paraffin) or wet and dirty towels used for washing after work are strong irritants.

The number and variety of harmful agents employed in industry is so great that specialist monographs must be consulted for a complete account of occupational diseases; the present paper must be confined to a few examples. Physical agents which may damage the body include excessive heat and cold, pressure, vibration, electricity, heat and light, radiation, X-rays and radioactive substances.

Physical Agents

Exertion in a hot and humid atmosphere causes loss of salt from the body through the sweat. Severe muscle cramps result, and may be relieved by drinking a solution of a teaspoonful of salt in a pint of water.

Caisson disease or 'bends' results when gas-bubbles of nitrogen are formed in the body. Nitrogen dissolves in the blood and tissues when a man is exposed to more than 20 lb. per square inch (a pressure which occurs at a depth of seven fathoms in the sea), and if there is too rapid a release of pressure, such as occurs when the ascent of divers to the surface is too quick, the dissolved gas forms bubbles *in situ* instead of having time to reach the lungs.

Airmen descending from high altitudes may suffer from severe pain in the ear, if the pressure on both sides of the ear drum is not kept equal. Inequality of pressure is likely to occur in the presence of nasal catarrh.

The careless use of pressure spray guns, employed to grease the springs of a car, may result in the injection of oil into the hands. Severe sepsis and gangrene follow.

Radioactive substances have been employed in industry for many years. During the first European War, in the U.S.A., in ignorance of their danger, girls were allowed to paint luminous dials without proper precaution, and many developed malignant disease (cancer). With proper screening of the radioactive materials, routine blood counts,

routine atmospheric tests for radiation, insistence on adequate holidays, work with radioactive substances is safe, a fact which was proved in the second European War when large quantities were used without harm.

Atomic energy is the latest industrial hazard. The principles of protection are the same as against any other harmful substances, but the power of penetration of the radiation produced in the atomic piles, and the long life of radioactive substances make screening and total enclosure very difficult. The insidious action of radiation makes careful medical supervision of workers and testing of their place of work for radiation absolute essentials.

Chemical Agents

Chemical substances may be absorbed in three ways; by swallowing, which is rare in industry, through the skin, especially if the substance is fat-soluble like aniline and its derivatives, and through the lungs. Gases, vapours, sprays and dusts breathed into the lungs may cause either direct effects on the lung or general poisoning of the body. Gases such as phosgene and chlorine, unfortunately well known in the first European War, have a direct effect on the lung; arsine, not uncommonly encountered in industrial processes, does not have any immediate effect on inhalation, but two or three hours later causes destruction of the red blood cells.

Many vapours, for example, benzene, trichlorethylene, methyl chloride, produce sudden insensibility if inhaled in high concentration. Over long periods the inhalation of lower concentrations causes damage to the blood, liver or kidneys. Chronic benzene poisoning is characterised by changes in the blood which, if allowed to progress, are irreversible. Routine examination of the blood of all persons exposed to benzene vapour allows the detection of early changes in the white cells of the blood, so that removal from exposure may be arranged even before the patient himself notices any symptoms.

In the chromium plating of metals, the passage of electricity through the bath causes the evolution of small bubbles of hydrogen. These bubbles are coated with a layer of chromic acid which is sprayed into the air as a mist when they burst, and on coming into contact with the nose this mist will cause perforation of the nasal septum.

Dust is the most difficult of all industrial hazards to control; because of its ubiquity, especially in places where suppression is difficult, silica dust is the greatest of all industrial hazards. Silicosis of the sandblaster, fettler, knife grinder, quarryman, goldminer, and pneumoconiosis of the coal miner and coal trimmer, all arise from the action of fine particles of silica on the lung.

Three principles must be observed in the prevention of industrial diseases; first a non-toxic substance should, if possible, be substituted for a toxic substance. A perfect example of this is the abolition of phossy jaw by the replacement of white phosphorus, used in the manufacture of lucifer matches, by phosphorus sesquisulphide (which is not toxic). The use of powdered aluminium instead of flint for bedding china promises a great reduction in silicosis in the pottery trade. Secondly, if abolition is not possible, the plant process or material should be totally enclosed. An excellent example of this is the manufacture of white lead paint; by the stack process, the white lead leaves the stack as an aqueous paste to which oil is added. Because of its greater affinity for oil, white lead pours from the water to the oil. By the old process white lead was ground and handled as a dry flake before solution in the oil. The resultant dust presented a grave hazard of lead poisoning.

For technical reasons, replacement by a non-toxic substance or total enclosure may be impossible and the third method, forced exhaust ventilation, has to be employed. Hoods, through which currents of air are sucked, are so arranged that the toxic material is drawn away from the workman (see Plate 26). Protective clothing such as goggles, gas masks and gloves is seldom entirely effective in

preventing industrial disease. It infringes Sir Thomas Legge's dictum as not being 'external to the workman'. For short periods and for emergencies it may have to be employed, but for prolonged working some other method must be adopted.

At all times, in the most unlikely places a most careful watch has to be kept for possible toxic risks. For example, small girls working in hatter's furriers shops may contract mercury poisoning from the mercury nitrate used to 'carrot' the felt. The old phrase 'mad as a hatter' associates the mental symptoms of mercury poisoning with the trade of a hatter.

Industrial Hygiene

Though the importance of toxic hazards to those exposed to them cannot be denied, comparatively few persons are subject to such a hazard in the course of their work. All persons are, however, exposed to general environmental conditions, and these may have an effect on their comfort and efficiency.

Temperature

As long ago as 1922, Vernon and Osborne showed that accidents were least in a group of workers performing sedentary work when the temperature of the factory was 65°F. Questioning of large numbers of people has shown that this is the temperature which the majority find most comfortable when undertaking similar work. Also, when workers are comfortable, production is increased; not only is the provision of a proper temperature at work humane, but also profitable.

Ventilation

Though the amount of ventilation needed will vary with the nature of the work, the size of the room and the number of persons in it, the requirement of 17 cubic feet of air per minute per person is a good and practicable standard

where no fumes or gases are present. Ventilation does not mean that draughts should be present; indeed if they are, the ventilation of a room is bad. The object is to change the air entering the room, if necessary warming it, without the change being perceptible to the occupants. At ordinary room temperature, an air current with a velocity of less than 40 to 60 feet per minute is not noticeable. With increasing speeds complaints of draughts tend to appear, but it is surprising how often a stream of warm air of a velocity of 120 feet per minute is unnoticed. For many factories, offices and shops, elaborate schemes of ventilation are not necessary. Properly opening windows, with radiators underneath, are usually adequate except where the floor space is very large or where a lot of obstructions to the circulation of the air exist. Where the work is hot, forced ventilation is nearly always necessary to keep the worker cool. Vernon (1940) showed that in tinplate rolling mills the decrease in output in the hot summer months was 18 per cent, but where cool air was blown on to the workmen the decrease was 12 per cent.

Lighting

The best form of lighting is daylight. In this country, artificial lighting should only be needed in factories not working at nights for approximately 15 per cent of the year. The characteristic of daylight is its great intensity (even on a dull day, daylight is equivalent to 200 foot-candles, and on a sunny day may be 1,000 or more foot-candles) and its diffuseness (i.e., it is emitted by a big source). So long as the intensity of illumination is adequate, the quality of the light matters little. For casual observation where no special work is performed, lighting of 2 to 4 foot-candles is sufficient. For ordinary visual tasks, such as reading and sewing, 10 to 15 foot-candles are required, but for precision work of a high degree of accuracy illumination of about 50 foot-candles is needed. Glare must be avoided, and this may be difficult with the higher illuminations, unless local sources

of light are arranged to illuminate the work and screened to prevent rays entering the eyes, either directly or indirectly by reflection from bright surfaces (see Plates 24 and 25).

In general, too much light is impossible (the accuracy of vision increases in proportion to the intensity of illumination until a level of 2,000 foot-candles is reached); insufficient illumination is a common fault. Illumination in coal mines, especially at the face, may be as low as a half foot-candle. Not only has this much to do with the high accident rate in miners, but it is also a major factor in causing nystagmus (oscillation of the eyeball). Probably the greatest single advance in mining methods would be the perfection of means to give adequate illumination in all parts of the pit.

Economy in the installation and maintenance of electric lighting is more than outweighed by the loss of production due to insufficient light. Dim and dismal conditions result in psychological depression, which is often referred to under the generic name of 'eye strain'. The maintenance of all sources of light is important; dirty bulbs, shades and reflectors may reduce the amount of light emitted by as much as half. The same applies to windows; these should be cleaned regularly both inside and out and, if possible, be of plain glass, as 'frosted' glass reduces the amount of light transmitted by as much as one-third.

Because fluorescent tubes provide a diffuse source of light, they more nearly approach daylight than tungsten bulbs. For this reason fluorescent tubes are to be preferred. If fluorescent tubes are properly arranged, flicker should not be noticeable. If flicker is present, this may be dangerous, as the moving parts of machines may appear to be still or even going backwards, if in appropriate frequency relation.

Noise

Suppression of noise seldom receives much consideration, but excessive and prolonged noise may cause permanent damage to the ear. Boilermaker's deafness is a well known

condition. Noise is a great distraction to mental work. This is not often a practical point, as few persons are called upon to undertake tasks requiring mental concentration in noisy conditions. Discontinuous noise, such as the tapping of a typewriter or a whispered conversation, are more distracting than continuous and sometimes louder noise.

Seats and Benches

Seats and benches should be designed to fit the worker so that the operator can, at choice, work either standing or sitting. For this, the working point should be $1\frac{1}{2}$ inches lower than the elbow height determined with the worker wearing shoes. This is much higher than expected, and for women the proper height for a bench is 36 inches where the thickness of the work is negligible (Lloyd Davies 1948). Adjustment of the height of the seat and foot-rest may be needed, but if benches are so arranged, not only are the workers more comfortable but the output of the same workers, using the same materials, is considerably increased. A classical example of the aching back and tiredness arising from the working point being too low is the domestic sink, which is often fixed at 19 inches from the floor. With the exception of hospital wards, no place would benefit more than the kitchen from the application of the principles of industrial hygiene.

Lifting

Unnecessary exertion should be avoided. Cranes should be used for lifting, as weight lifting, especially if continuous, is a potent cause of fatigue. Persons vary in the amount of weight they can lift, and Table IV shows the maximum loads for *experienced* workers.

Loads should be compact and lifted with the knees flexed, so that part of the strain is taken by the thighs and legs as well as the back.

TABLE IV

Maximum loads for Lifting by Experienced Workers.
(from *Weight Lifting by Industrial Workers*, 1944.
by permission of H.M. Stationery Office).

Men		130 lb. compact load.
Women		65 lb. (Intermittent work).
		50 lb. (Continuous work).
Young persons of 16-18 years	Male	60 lb. (Intermittent work).
		45 lb. (Continuous work).
	Female	56 lb. (Intermittent work).
		40 lb. (Continuous work).
Young persons of 14-16 years	Male	30-40 lb. Female 35-40 lb.

Continuous lifting: this term is used to denote lifting of one ton or more a day. A load of 40 lb. lifted seven times per hour for eight hours totals a ton.

Social Aspects of Industry

1. *Hours of Work*

The 1833 Factory Act limited the hours of work of children nine to thirteen years of age to nine hours, and young persons thirteen to eighteen years of age to twelve hours a day. Night work and overtime were forbidden. By modern standards, these were long hours to work children too young to be employed in factories. When the 1847 Act reduced the permitted hours of young persons and women to ten a day, both factory inspectors and factory owners were surprised that no loss of production resulted. Ten hours remained the legal maximum until the Factories Act 1937 reduced the permitted hours of work for young persons under sixteen years of age to forty-four, and for young persons sixteen to eighteen years of age, and women to forty-eight a week. The hours men may work are not controlled except indirectly, as it is usually unprofitable to keep men at work when their women colleagues are released.

When excessively long hours are worked (except for very

short periods) health and efficiency are impaired. The absentee rate increases and the output per hour drops. Shortening of hours results in a rise in hourly production and in total output; for example, reduction of hours of work from $74\frac{1}{2}$ to $55\frac{1}{3}$ per week resulted in the hourly production rising from 108 to 169, and the weekly output from 7,128 to 8,028 (Vernon 1920). For continued periods, forty-eight hours a week is the optimum working time. Health is not impaired and production is at its best. No evidence exists that shortening of hours below this level either improves health or increases output.

2. *Fatigue*

As spoken of in industry, fatigue is the departure from full health which arises from the strain of a prolonged exposure to trying conditions. Profound as is the effect of environmental conditions on the occurrence of fatigue, of even greater importance is the relationship existing between human beings within industry. The greatest stress of all is unhappy relations with other workers or with superiors.

Fatigue is manifest by irritability, susceptibility to minor illness which raises the absentee rate, increased liability to accidents, and by loss of production. Long continued fatigue results in strikes and high labour turn-over.

Until Bartlett's (1943) crucial experiment, theories about the origin of fatigue bore little relationship to industrial conditions. In this, under conditions where physical work was minimal, experimental subjects were required to perform highly skilled tasks requiring mental concentration. As the subject became fatigued, the right action was performed at the wrong time, the stimulus field split up and became an unconnected series of signals for action. The standard of performance deteriorated, but the subject believed he was doing better than he was. Finally the subject showed extreme mental irritation, and blamed the machine and not himself in no uncertain terms.

Conditions of such intense stress do not occur in industry,

but long-acting minor stresses will produce a condition of mental irritation, exhaustion and chronic fatigue. This may cause a high rate of leaving or be the hidden reason for strikes, which are a collective means of behaving unreasonably. The frequency of strikes in the bus industry may be connected with the strain of driving, and as such may be regarded as an occupational disease.

Temporary illness, such as colds and influenza, increases susceptibility to fatigue, and conversely fatigue increases susceptibility to illness. Some persons, especially the over-conscientious and anxious type, are more susceptible to fatigue than others, and will break down in conditions which do not affect the majority of persons. Fatigue may be relieved by rest from work, either in the form of shortened hours of work, a holiday or change of work, but care and prevention depend on the removal of industrial and social causes of strain, reinforced by appropriate psychological investigation of the individual patient.

3. *Fitness for Work*

The definition of capacity or incapacity for work has long presented difficulty to the administrator. The state of health or sub-health of the industrial population is such that the majority of workers may properly, and at their choice, declare themselves fit or unfit for work (Ferguson 1945). Minor variations in circumstances such as a cold, or exposure to trying industrial conditions, may result in variations in fitness for work. Change of job surprisingly often results in a successful return to work. Such incidents are not to be despised as a lack of desire to work, but rather as the loss of keenness and interest when work is boring or disliked. A manager or foreman himself suffering from symptoms of anxiety or obsessional traits, may so irritate his subordinates as to cause a high incidence of nervous illness. Knowledge of when to turn a blind eye is a great asset, but when direction is needed, this must be given fearlessly and confidently.

Absenteeism is, therefore, a good index of morale both of the individual worker and the group. If a worker is bored, a minor illness such as a cold, or even the thought of getting out of bed on a cold day, will result in absence. A worker who is keen and interested in his work will make every effort to be at work, often when he is really too ill to be there. Many workers have resented being sent home compulsorily after turning up for work, when suffering from serious illness such as pneumonia. Whether inability or disinclination to work is declared as sickness, or manifest as voluntary absenteeism, is fortuitous. Sick absence is partly the reflection of the health of the community and partly the reflection of individual keenness to work, or in modern jargon, of job adjustment. Lack of job adjustment will cause absence to result from trivial complaints (which otherwise would not affect fitness for work), and also may be causative in vague conditions such as debility and neurasthenia. In marked degree, lack of job adjustment, especially in a predisposed person, will cause neurosis.

Experience has shown that with good working conditions and happy workers, a total absentee rate of 5 per cent for men and 9 per cent for women may be expected, of which 3-4 per cent and 5-6 per cent respectively will be due to sickness. Accepting diagnosis as made by the patient's doctor, the distribution of sickness will be approximately as shown in Table V.

Russell Frazer (1947) recently observed a group of light engineering workers, and found absence due to neurosis to be nearly 30 per cent of the total sickness. Whilst the amount of neurosis in the community is seldom realised, the difference may be due to the fact that Russell Frazer's investigators were psychiatrists. In considering the higher rate of absence from work amongst women, account must be taken of the fact that many women have other responsibilities. Absenteeism and sick absenteeism must always be considered in the background of the total situation.

TABLE V

Approximate distribution of Sick Absence.

Due to		
Infectious diseases (including colds and influenza)		30 per cent.
Respiratory diseases		25 per cent.
Digestive conditions		20 per cent.
Psychological conditions	men	5-10 per cent.
	women	10-15 per cent.
Rheumatic conditions		5-10 per cent.
Skin conditions		5-10 per cent.
Occupational injuries (including occupational skin conditions.)		2-10 per cent.

4. *Reasons for Work*

The choice of work is the most important thing about work, and the tragedy is that, in this country, so few persons have in the past had freedom to choose their work. Economic pressure, parental ambition and social snobbishness, may force persons to undertake work which they do not like and for which they are not fitted. Work is done for many reasons; to earn wages, to earn the power that wages bring, to deaden thought, to earn leisure, to express artistic instincts or to give vent to 'malice, hatred and all uncharitableness.' The most important reason why work is done is often ignored. Work is a social habit. The Hawthorne Experiment (Whitehead 1938) began in 1927, when five girl relay assemblers started work as a separate group. For six years, working conditions were varied, and the resulting alteration in output noted, but toward the middle of the period it was realised that the very fact that a change was being made was always favourable, because of the attention to the group the change involved. Each operator judged her working situation as a whole, and in terms of its social significance, i.e., in terms of her relationship with her fellows and with the outside world.

Work is the means by which the creative instinct is ful-

filled; not all persons are capable of the creative heights reached by an artist, but all but the smallest minority have a strong urge to do something useful. Craftsmanship is an attitude of mind; from materials of which he has the 'feel', the craftsman fashions with infinite care an article which is a perfect blend of beauty and usefulness, and in so doing fulfils a social function. Work to a craftsman is joy.

Under modern industrial conditions, craftsmanship is no longer possible or attainable by the majority of persons. Work has become a dull necessity so that incentives to production must be discovered. Even if incentives in themselves are highly laudable, for example, service to the community, they are separate from work. Work itself is no longer its own incentive.

The urgent need of modern industry is to substitute pride of achievement for the lost craftsmanship of earlier ages, so that work is done for the sake of the work. The function of management is to create good conditions of work and to provide work in which pride can be taken; the function of labour is to seize the chance of work under good conditions, and to be proud of its work. Only in this way can man become whole; for without pride of achievement he will for ever be frustrated. Work is a primary need of the healthy man.

In this, all engaged in industry need the help of educationists. The Education Act 1918 required the establishment of Day Continuation Schools, but because of the economic depression, except for the town of Rugby and a few large companies, none were established. In one Day Continuation School, established in 1920 jointly by Boots Pure Drug Co. Ltd., and Nottingham Education Committee, all young persons aged 14-16 years were required, as a condition of employment by the Company, to attend the school one half day a week without loss of wages. The curriculum provided a liberal education with a strong biological bias. At a time when adolescent doubts, fears and loneliness present pressing and urgent problems, the young person

was placed, for one half day a week, in a discipline which sought to resolve his problems and to help him to find a moral basis and purpose in life. The compulsory extension by the Education Act 1944 of part-time education to all young persons under 18 years of age (not already attending a whole-time course of instruction), wherever and however employed, will prove to be the greatest measure which has ever been enacted for the social good. From April 1950, for one whole day a week (or the equivalent), County Colleges will bring to all employed young persons the academic freedom and understanding of the university.

If men with free and unfettered minds are to be healthy, work must no longer be thought of in terms of whether it is harmful, but whether it is beneficial to man and mankind.

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Cold Welding of Aluminium

LAWRENCE E. HUDSON

THE past decade has seen an intensive search for a method of joining aluminium, particularly because of its use in aircraft construction. No simple reliable process has resulted. Both gas and electric arc welding require elaborate equipment to prevent oxidation of the reactive metal, by provision of an inert atmosphere. Soldering compounds have been developed but have never achieved large-scale acceptance. Riveting, still the most used technique, establishes a source of weakness all too familiar to the user of aluminium saucepans.

Whilst all this effort was being focused on the problem, the simplest possible solution awaited discovery.

That formula is simply, first, clean up the surface, so that the body metal is revealed; then, squeeze together (in dies of special design) the two parts to be joined, until their combined thickness has been reduced by a percentage which depends upon the metal being used. When this percentage reduction is reached, the identity of the boundary between the two parts is lost, and a true weld forms between them, even though this process is carried through at ordinary temperatures.

It seems unbelievable that it can happen, and then, when the truth of the prescription is demonstrated, it is equally hard to understand why the process has never been discovered before. The secret lies in the detail.

First – the cleaning. Its object is to remove the layer of oxide which is formed on the surface of most metals by reaction with the oxygen and moisture in the air. Nor is this removal easy, for it must be done by a process which

also clears away all the debris arising in the cleaning. Chemical methods are ruled out straightway, since any simple procedure must end with washing to remove the solvent, and that washing would immediately re-form the oxide layer it is seeking to remove. Nor are ordinary mechanical treatments such as filing or rubbing with abrasive more successful. In both, material removed early is re-embedded in the surface by later working. In the latter, the situation is made worse because particles of the abrasive itself are also left embedded in the surface.

Use of a power-driven rotary scratch-brush is the ingenious solution which was evolved and applied in the G.E.C.'s Research Laboratories. The steel wires of the brush break through the oxide layer and seize upon the surface of the metal beneath. Fragments, with their adhering oxide, are torn loose, and flung clear because of the high speed at which the wires are moving. So a fresh metal surface, free from oxide and dust, results. Moreover, the oxide film re-forms slowly, so that welds may be made several hours later, provided that there has been no contamination by moisture or grease. This requirement is most stringent, for even the contamination carried by a single handling will make welding impossible.

Second – the percentage reduction in thickness. As the thinning is increased, the two parts show an increasing tendency to stick together, but not until that necessary minimum, characteristic of the metal, is reached, does a true weld form. Once that reduction has been achieved, it is obviously undesirable to exceed it and so merely to weaken the metal without purpose. So all tools, presses and so on must be arranged with stops preventing closure of the dies beyond this minimum. Related to this minimum is the *figure of merit* used to compare weldability of metals – the maximum percentage of the double thickness which can remain when a sound weld is to be formed. The following table gives the figure of merit for the several metals and alloys which have already been investigated.

Material	Figure of Merit
Super-pure aluminium	40
Commercially pure aluminium	about 30
DTD 34D	29
BA 60A	20
Duralumin	20
Cadmium	16
Lead	16
Copper	14
Nickel	11
Zinc	8
Silver	6

Thus, to give a weld, two pieces of pure aluminium each $\frac{1}{16}$ inch thick must be squeezed until their combined thickness is only $\frac{1}{20}$ inch – and two pieces of silver of the same thickness must be compressed to only 6/800 inch. In the first case the process is useful – and in fact by proper design and location of welds, joints can be produced which are as strong as the original strip of aluminium. In the second case, the thickness has been too greatly reduced for cold-welding to give practically useful results. Aluminium and some of its alloys, and, because its greater intrinsic strength counterbalances the increased reduction required, copper, fall into the first class. All other metals so far examined fall into the second class.

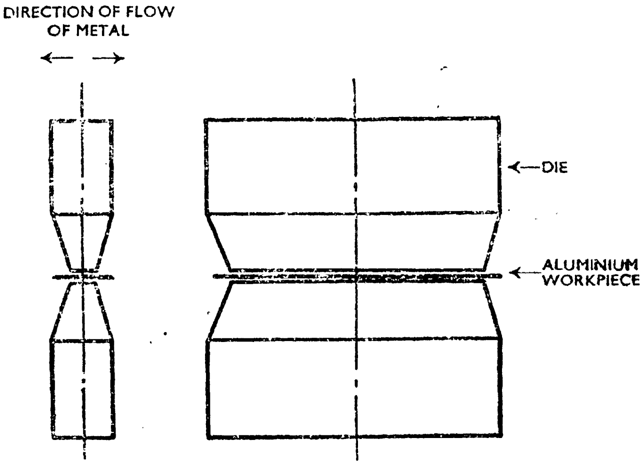

Fig. 6. – A pair of dies for pressing two pieces of aluminium into one continuous piece; end view on left, side view on right.

The last detail to which attention must be given is the design of the dies. Fig. 6 and Plate 15 shows a pair of the simplest form. All must have this in common – that they are narrow in one direction so that the metal can flow easily away from the weld in the other dimension. Other than this, there seems to be no restriction, and dies of many complicated shapes have already been evolved for special purposes.

So much, and satisfactorily, for the details of the 'invention' – but when the matter is viewed as a scientific phenomenon, standing in need of explanation, the situation is less satisfactory. So far, there has been time only to put the phenomenon to service in the solution of urgent problems. The systematic metallurgy needed for its explanation is only now being carried through. A plausible mechanism can be suggested, but its truth cannot yet be guaranteed.

A strip of metal is normally made up of a large number of crystallites of irregular shape – whose interlocking gives the

metal its strength; the smaller the crystallites, the more interlocking and the greater the strength of the metal. Each boundary represents the local relief of the strain caused by inability of two crystallites to accommodate their orientations one to the other. When the metal is heated, there is generally an overall relief of strain, in that larger crystals tend to grow at the expense of the smaller crystals, and the metal becomes softer. This is the effect of annealing. Strain- or work-hardening is the reverse process. The strains caused by working are relieved locally by the break-up of large crystals into smaller, so that interlocking is increased and hardening results.

In the smith's method of welding iron, the two parts are worked together by hammering at a high temperature. At that high temperature, recrystallisation can take place more easily. Strains are induced within the metal by hammering, but those strains are relieved almost immediately by readjustment of the crystal boundaries. In this readjustment, crystals grow across the interface between the two pieces of metal and, interlocking with crystallites in both pieces, hold them together in a true weld.

In the cold welding process, it is thought, the first effect of pressure is to cause strains, which are relieved by a break-up of crystallites into smaller units. It seems likely that, as the internal strains increase, the temperature needed to release them will fall. There is evidence for this supposition from powder metallurgy (See *Science News* 1, page 63). There it is found that sintering temperatures fall as grain size is decreased. It is suggested that, in metals which cold-weld easily, grain size may fall so rapidly under pressure that recrystallisation can take place in the cold metal. Then, as in the blacksmith's weld, the two parts are held together by those crystals which, growing across the interface between the two parts, completely destroy its identity.

Before this explanation can be accepted, many features will have to be fitted in; perhaps the strangest of them is that aluminium is welded easily and silver only with difficulty,

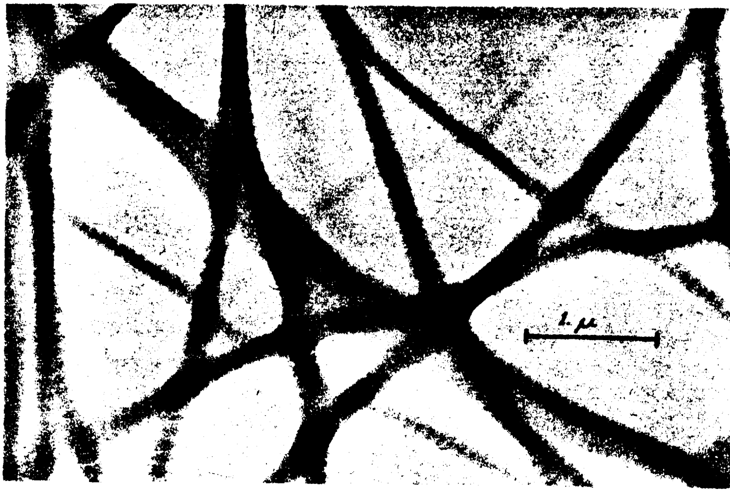

Plate 1. Electron micrograph of collagen fibres teased from guinea pig Achilles Tendon, showing cross striations 640 Angstrom units apart. $1\mu = 10^{-4}$ cm. = 10,000 Angstrom units.

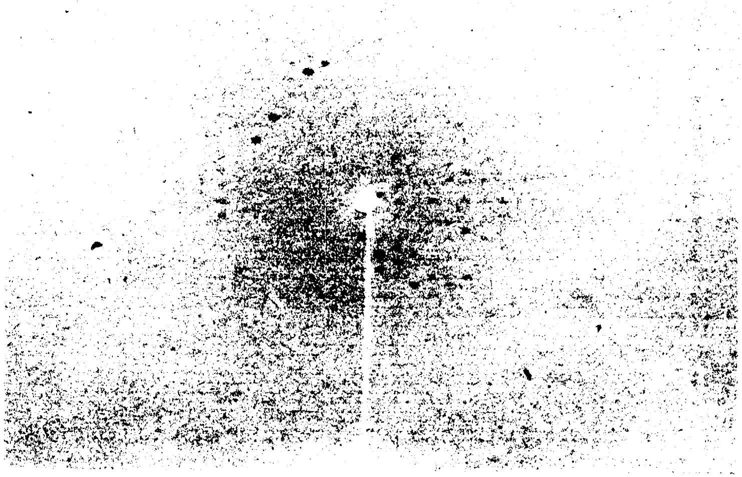

Plate 2. X-ray diffraction photograph of a sheep haemoglobin crystal.

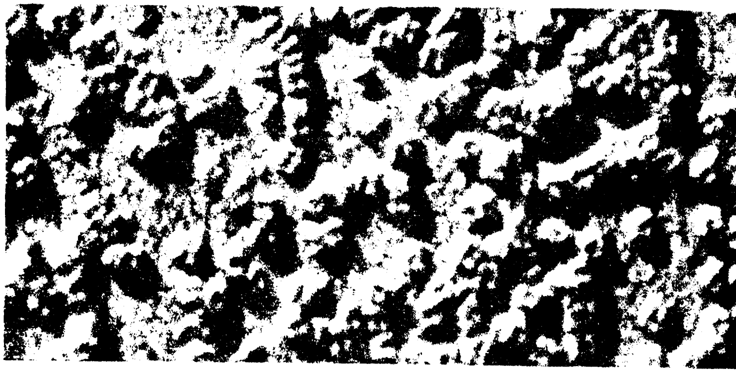

Plate 3. Electron micrograph of molecules of haemocyanin spread on a glass surface. Individual molecules are the cube-like objects. Magnification x 77,000.

Plate 4. Electron micrograph of parts of two crystals of southern bean mosaic virus, showing the individual molecules of virus arranged in a regular array. Magnification x 23,000.

Plate 5. Electron micrograph of fibril from molluscan muscle, showing discrete spots which lie on diagonals which make different angles (α and β) with the axis. (*Courtesy of the Journal of Applied Physics*).

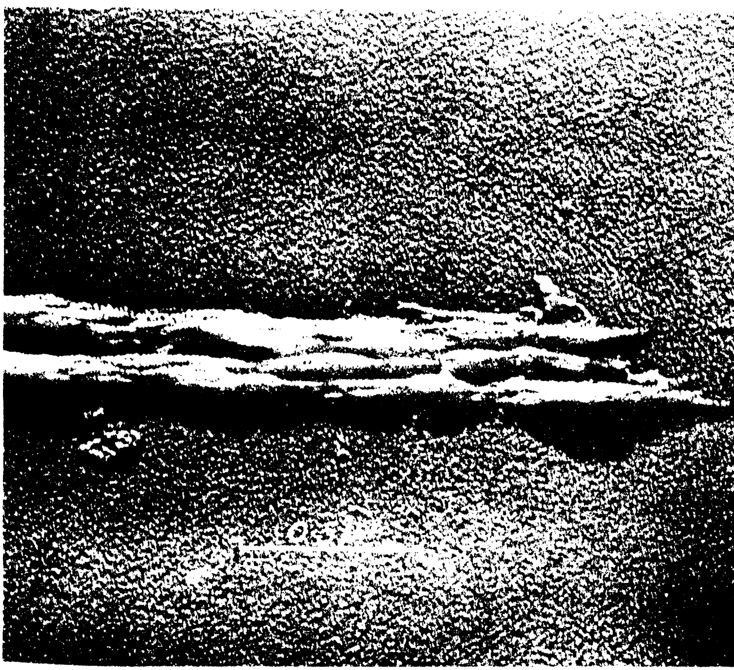

Plate 6. Electron micrograph of fibrils isolated from cortical cells of wool, indicating the subdivision into proto-fibrils and showing the particulate structure of these.

LIFE IN GRAHAMLAND

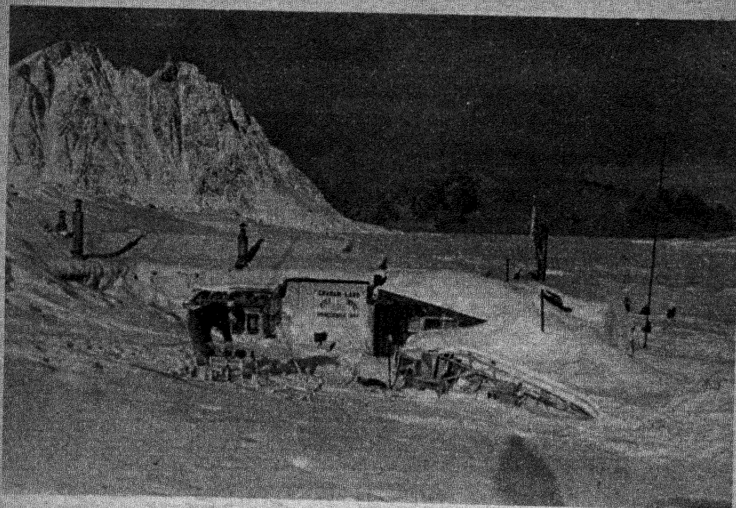

Plate 7. The base hut in Grahamland covered in snow. Note the radio mast to the right.

Plate 8. A tent pitched on the trail, with the outer layer turned out, and a ration box placed on it, as described in the text. Note skis to the right.

Plate 9. Midwinter's party, July 22nd.

Plate 10. The workshop of the Grahamland base.

Plate 11. A dog team at work on the sea ice. The mountains in the background rise to 3,000 ft.

Plate 12. Adélie Penguins.

Plate 13. Outdoor clothing for Antarctic travel.

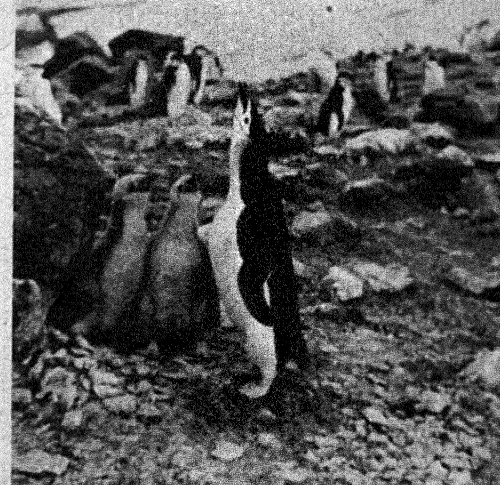

Plate 14. Ringed Penguin with chicks.

COLD WELDING OF ALUMINIUM

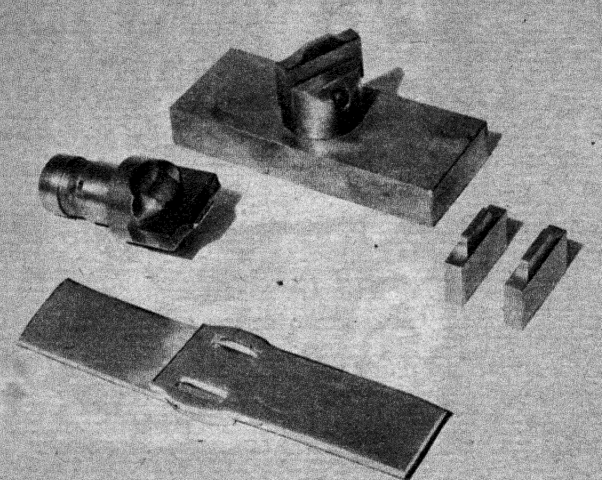

Plate 15. Simplest form of dies, as used for making short straight weld shown in foreground.

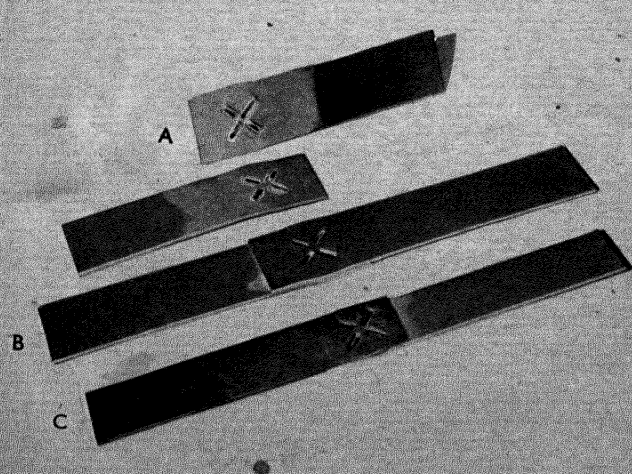

Plate 16. Strip-joints of aluminium (B) and aluminium to copper (C). (A) shows a typical tensile failure.

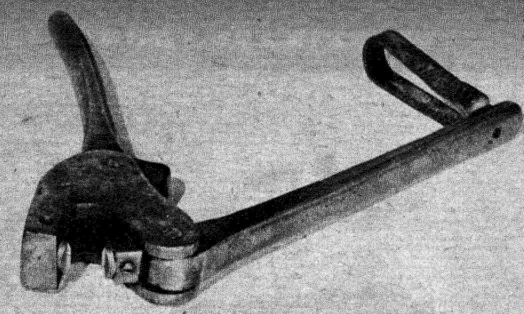

Plate 17. A Hand-Tool adapted for cold welding.

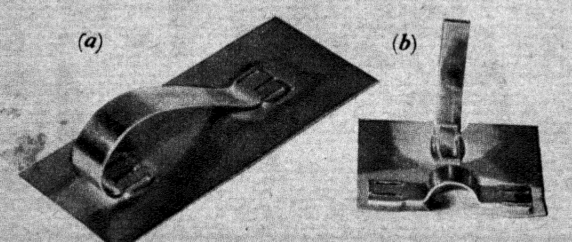

Plate 18. Specimen applications of cold pressure welding of aluminium. (*a*) handle fixed to plate, (*b*) strip joints fixed to plate.

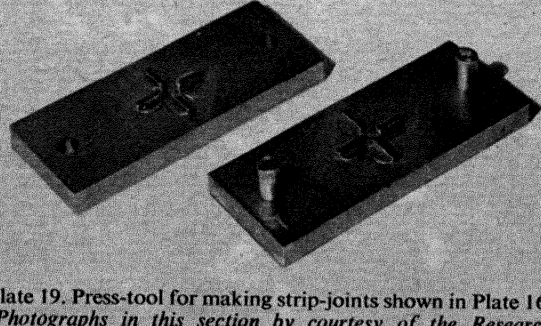

Plate 19. Press-tool for making strip-joints shown in Plate 16. (*Photographs in this section by courtesy of the Research Laboratories of The General Electric Company, Limited, Wembley, England*).

Plate 20. 'Pining lamb' with healthy lamb of same age.

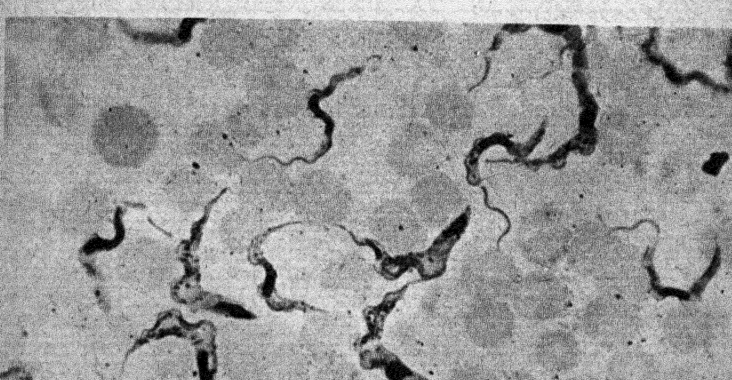

Plate 21. *Trypanosoma brucei*, the cause of nagana – a disease transmitted by tsetse flies. The parasite is seen among the blood corpuscles, and is about 0.02 mm. long.

Plate 22. Immature Fluke in Liver Tissue. The size of the adult can be up to 3 cms.

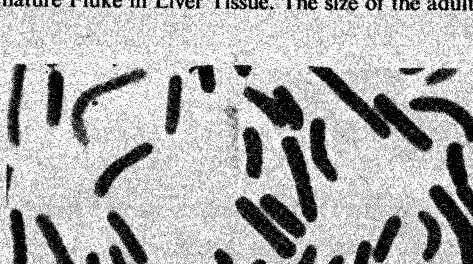

Plate 23. *Cl. oedematiens* – the bacteria which, with the liver fluke, cause Black Disease in Sheep. Magnified 2,000 times.

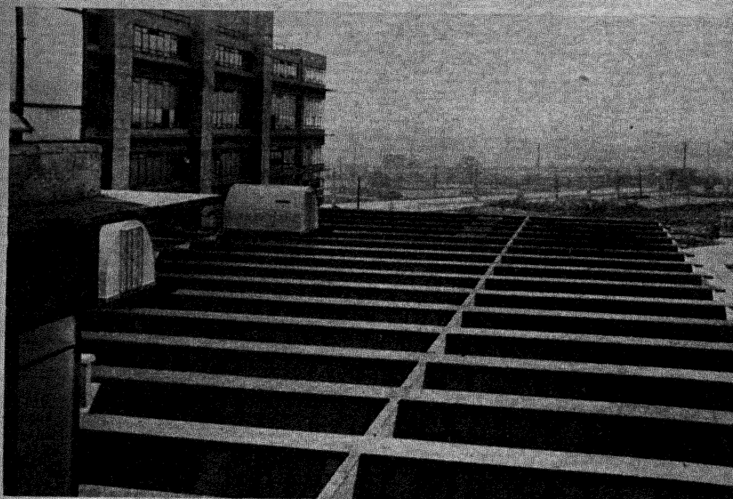

Plate 24. A view of the roof of a modern factory to show the system of north lighting. The huts on the roof house the intake fans for the ventilation system. The output is through the shafts rising up the sides of the multi-storey section on the left.

Plate 25. The same factory from the inside. Good general lighting is obtained without glare. The louvres running along the far wall are where air enters the factory. Note the arrangement of benches and seats.

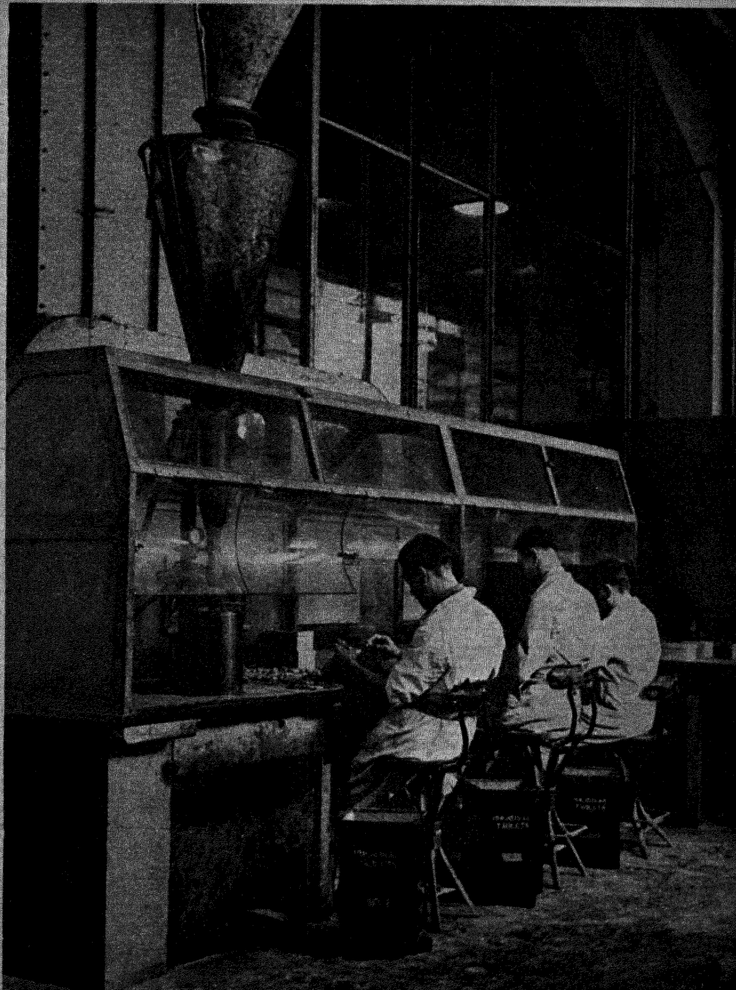

Plate 26. Phenosan (phenothiazene) when inhaled is metabolised in the body to leucothinol, which is photosensitive so that if the skin is exposed to the sun an acute burn appears. Exhaust draughts draw the air away from the operator, preventing dust from being inhaled. Curved Perspex screens allow clear vision. Note height of seat in relation to bench height and back support. (Phenosan is used for the control of worms in livestock including cattle, sheep, horses and poultry).

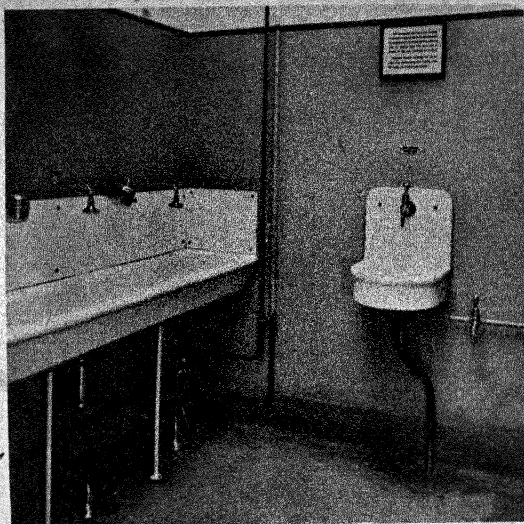

Plate 27. A Works Washroom. Foot controlled water supply allows hands to be washed in flowing water; not only is less water used but the wash basin remains clean. Note the supply of liquid soap and drinking tap. The floor is grano which can be washed down.

AURORA BOREALIS

Plate 28. Photographs of aurora showing the six exposures on one plate, two of corona and four of rays.

Plate 29. Corona photographed at Abernethy, Perthshire, on the night of March 23-24, 1946. Note the resemblance to cirrus clouds.

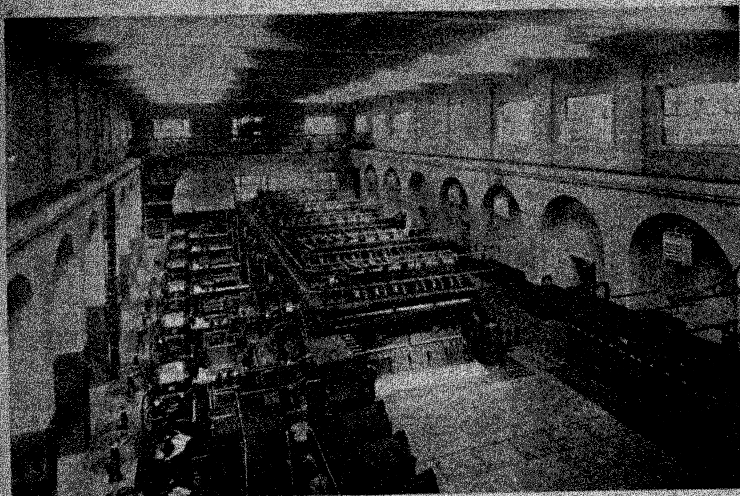

Plate 30. The Pumping Station at Mogden. The vertical scale on the left registers the depth in the suction sump of sewage to be pumped to the upper level.

Plate 31. Aeration channels showing mixture of sewage and activated sludge being agitated by compressed air. (*Both photographs by courtesy of the Middlesex County Council*).

where instinctively, one would expect the reverse. The eventual story may also have reference to that natural freak, indium. If two pieces of this very rare metal are merely left in contact, they become welded together at ordinary temperatures.

Meanwhile, applications of the technique multiply in number. Already it is being adapted to continuous processes and, at the other end of the scale, to hand methods suitable for use in the amateur's workshop. Its results will soon be seen in several fields. It will encourage the replacement of steel by aluminium and it may well cause basic changes in the methods of many industries (see Plates 15 to 19).

Streptomycin on Trial

DR P. D'ARCY HART

THE outstanding event of the war in medical treatment was the British discovery in 1940 of the power of penicillin to prevent and control various types of infection. Apart from its immediate practical benefit to mankind, this discovery directed afresh the attention of laboratory research workers to a class of chemotherapeutic agents now called 'antibiotics,' and to a source of these agents having indefinite potentialities, namely, the soil.

An antibiotic substance may be defined as a chemical substance produced by a micro-organism (bacterium, mould, etc.), and found to stop or slow down the growth or activity of other species of micro-organisms. It contrasts with a purely synthetic agent (e.g., a sulphonamide), invented by the organic chemist and having no known counterpart in Nature. The antibiotic penicillin is, of course, produced by a mould, and it is remarkable that this, as well as most of the micro-organisms that yield antibiotics – be they moulds, actinomycetes (see below) or bacteria – have the soil as habitat; soil and medical microbiology have thus become interconnected in a new and fascinating way.

The microbiologists taking part in this intense search for antibiotic production amongst soil micro-organisms included Prof. Selman Waksman and his colleagues in the U.S.A., who were led in this way to the antibiotic, streptomycin. Streptomycin is a product of *Streptomyces griseus*, a species of the Actinomycetes family (which might rather loosely be considered as half-way between the moulds and the bacteria), and it is interesting that only certain strains of the species are productive. Purified strepto-

mycin is a basic substance, whose chemical formula is known to be $C_{21}H_{39}O_{12}N_7$, but which has not been synthesized. It is remarkable not only for its antibacterial properties but because of its low toxicity, which permits its use in effective doses in animals and man – in this respect it is the most advantageous antibiotic since penicillin.

Streptomycin is active against a number of micro-organisms, producing diseases in man which do not respond to penicillin. Thus it has already found a place in the treatment of certain infections of the urinary tract (pyelitis, cystitis, etc.) due to 'gram-negative' bacilli such as *Bacillus coli;* in the treatment of tularaemia, a disease rare in this country but more frequent in America; in certain rather rare acute forms of meningitis, including that due to the so-called 'influenza' bacillus; and it shows promise in plague and (in combination with sulphonamide drugs) in the milk-borne infection, brucellosis (Malta fever). But in Europe its most important use is undoubtedly in tuberculosis.

Man usually becomes infected by the tubercle bacillus by way of the air passages and lungs, through inhaling the cough spray or dust-borne expectoration of persons suffering from pulmonary tuberculosis; but infection may also arise by way of the food passages and intestines, through drinking the milk of cows suffering from tuberculosis of the udder. In this country so frequent are such contacts that most persons become infected before reaching adult life. Sometimes this 'primary infection' leads to obvious and even fatal disease, especially in infants; two formidable clinical examples are (*a*) acute generalised (or 'miliary') tuberculosis – when small tuberculous nodules are formed in many of the organs as a result of scatter of the bacilli through the blood stream, and (*b*) acute tuberculous meningitis – when, sometimes as part of a generalised spread, the membranes covering the brain become grossly inflamed and symptoms relating to the central nervous system develop to the accompaniment of fever. In another small minority, primary infection is followed by chronic non-pulmonary

forms of tuberculosis affecting, for example, glands or bones and joints. In the vast majority of children, however, the lesions produced by primary infection are minute and this event passes unnoticed and without causing trouble.

Most people in Britain, therefore, reach adult life having overcome successfully a primary tuberculous infection. Pulmonary tuberculosis (i.e., tuberculosis of the lungs) in adults occurs as a result of fresh outside infection overcoming this resistance, or because bacilli in apparently healed areas of the body re-awaken into activity; it may also be the direct consequence of primary infection in a number of those who receive this later than usual, when already adults.

Pulmonary tuberculosis starts typically as a microscopic area of tissue cells and exudate, formed in response to the invasion of the lung by inflammatory bacilli from the smaller air passages, usually in the upper part of one lung: the local air sacs become de-aerated and blocked. The infection and reaction (tuberculous bronchopneumonia) spread by the smaller air passages and local lymphatic channels to adjacent or nearby portions of the lung. Tuberculous areas formed in this way are big enough to be seen with the naked eye. The next phase in the struggle between the body defences and the infecting micro-organisms is often that the centres of these tuberculous formations break down into cheesy pus or dead 'caseous' matter; further destruction of the lung tissue through the tuberculous process may lead to ulceration into a small bronchial tube or air passage and leave a hole in the lung ('cavitation'); such a patient may have considerable sputum laden with tubercle bacilli. When the patient's resistance is reasonably high, another tendency is towards fibrosis (formation of scar tissue) and healing – hence the term fibro-caseous tuberculosis, which is the commonest chronic form; fibrosis usually surrounds cavities of long standing.

According to the predominance of any one of these phases, the form of pulmonary tuberculosis varies. One

may have the relatively uncommon acute progressive pneumonic type affecting both lungs (in which substantial areas become solid with inflammatory exudate filling the air sacs); in spite of its association with a low resistance in the patient, this type should be accessible to drugs introduced into the blood stream, and is so labile that it might be expected to lend itself to chemotherapy. One may have smaller editions of the active spreading stage, also without much fibrosis. One may have the relatively common chronic fibroid or fibro-caseous type, with thick-walled cavities; although the resistance of the patient is here manifestly high, the lung condition is clearly less accessible to the action of chemotherapeutic agents, as well as being mechanically stable.

From this brief account, tuberculosis is protean in its manifestations; further, most of us have received an infection with living bacilli but have, for practical purposes, 'cured' it without necessarily eradicating all the infection. These points have to be borne in mind by research workers who are seeking a chemotherapeutic remedy. Not only is the search particularly difficult in this disease, but even though a drug may seem promising in the test-tube or in experimental animals, its efficacy is still difficult to assess in man – the history of tuberculosis contains many apparent 'wonder cures' for tuberculosis that came to nothing.

Streptomycin was so remarkably better than anything previously tested in the laboratory that its trial in man was approached with some confidence. Early work in the U.S.A. in 1946 proved that the drug had, at least temporarily, life-saving effects in a small proportion of certain acute forms of tuberculosis, such as tuberculous meningitis and miliary tuberculosis (see above), which had hitherto proved almost invariably fatal. These results have been confirmed and extended in trials organized in this country by the Medical Research Council on behalf of the Ministry of Health. The Medical Research Council results emphasize among other things the vital importance of detecting cases

of tuberculous meningitis at the very earliest stage possible and instituting treatment at once, for the earlier the treatment starts the better the outcome in this disease. Further work in America and this country has established the benefit of the drug in tuberculous ulcerative conditions of the larynx and trachea (wind-pipe) and in certain types – though the minority – of pulmonary tuberculosis, namely, those in which a small or a large part of the lungs has been recently involved in a progressive tuberculous bronchopneumonia (again see above), e.g., in a flare-up complicating an apparently quiet case. Streptomycin appears to be of little value in the more common chronic forms of the disease with fibrosis and cavitation. The drug relieves some of the symptoms in tuberculosis of the kidney and bladder, but the permanent effect is still doubtful. Results in bone and joint tuberculosis have so far been inconclusive.

Another streptomycin trial, carried out by the Medical Research Council, is notable in that (*a*) a category of pulmonary tuberculosis (both lungs affected with acute progressive tuberculosis of recent development in young adults) was selected to provide a stern test and (*b*) the trial was controlled statistically, that is the treated cases were compared with a parallel series of similar cases treated by the ordinary methods alone. This was achieved by first selecting a case as medically suitable to be included in the trial, with the aid of a panel of clinicians, and then assigning the case – on the basis of a system of randomization prepared beforehand – either to the streptomycin group or to the group to be treated by ordinary methods. Restriction in this way of streptomycin to half the patients was fully justified by shortage of supplies. This controlled trial has shown evidence of the benefit of the drug in a clearer manner, susceptible of statistical analysis, than has any previous inquiry.

The standard method of administering streptomycin in tuberculosis is by one or more injections daily into the muscles; this route gives a good distribution of the drug in the body. However, in meningitis it is necessary to give,

as well, one or more courses of injections into the fluid surrounding the spinal cord and brain (cerebro-spinal fluid). In some tuberculous conditions, e.g., where a deep abscess communicates with the skin surface, additional local application is useful. The drug cannot be given effectively by mouth since it is very poorly absorbed from the stomach and intestines. The best length of a course of treatment in tuberculosis is still a matter for trial, but (apart from meningitis where the procedure is intricate) a usual course would be 1 gramme daily intramuscularly for three months. Long follow-up of cases by X-ray, etc., after the conclusion of treatment, is essential; and tests of how far the bacilli have become resistant to the drug (see below) are necessary for as long as these can be isolated from the patient. Streptomycin prices are unstable, but the cost of a three-month course of one gramme daily might lie between £50 and £75.

There are two serious obstacles to streptomycin treatment. One is that, unlike penicillin, it has a certain though not an alarming toxicity, particularly affecting the balance mechanism associated with the nerve of hearing (8th nerve). While the toxic effects can be disregarded when streptomycin is used in a life-threatening condition, the physician must take the risk into account when using it in less serious forms of tuberculosis. The other obstacle is that the tubercle bacilli in the body, at first highly sensitive to the drug, are liable after a few months' treatment to be resistant to its action so that the curve of clinical improvement may flatten out and a second course of treatment be useless. This means in effect that streptomycin may only be able to be used once in a given case. Both toxicity and the development of resistance may eventually be avoided by new modifications of the drug or by its combination with other agents. At present, however, these effects contra-indicate the use of streptomycin in cases of tuberculosis likely to benefit from ordinary methods of treatment (e.g., bed-rest and/or collapse therapy) alone. Early cases with

favourable outlook would be an example of such contra-indication.

Clearly then, streptomycin is not a 'miracle drug', nor a 'cure-all', nor a '24-hour treatment'. It gives rapid benefit to a proportion of a minority of types of tuberculosis, though this benefit may not be permanent. The drug is to be considered at present as supplementary to the ordinary methods at the disposal of the physician – collapse treatment, bed-rest, diet, etc. – and not a substitute for them; in fact its major rôle may prove to be to make possible the use of collapse measures, e.g., artificial pneumothorax (See *Science News* 4, p. 15) which otherwise might have had to be delayed or never performed. Certainly streptomycin must not be given indiscriminately.

In 1946 and 1947 all the small amount of streptomycin available in this country had to be purchased from America by the Ministry of Health, and was allocated to the Medical Research Council for trials in tuberculosis and in the other conditions (some of which have already been mentioned) in which the drug showed possibilities. Acting on the early results of the first of these trials, the Ministry in the latter part of 1947 arranged that a number of centres should be opened for miliary and meningeal tuberculosis and (in 1948) for ulcerative tuberculosis of trachea and larynx. At the time of writing (October, 1948) there has been as yet no official release for pulmonary tuberculosis, but, on the basis of the statistically controlled Medical Research Council trial (see above), together with other results, such a release can be foreseen.* Meantime, British production has been started and it is expected that in the coming months it should be sufficient to supply domestic needs in all the varieties of tuberculous and non-tuberculous disease for which streptomycin's usefulness has been established. Strict care, however, will continue to be required in the administration of

*Since this article went to press, the Ministry of Health has extended the allocation of streptomycin to the Regional Hospital Boards, so as to permit the treatment of certain types of pulmonary tuberculosis.

the drug, and proper X-ray and laboratory facilities to be available; its use will possibly be limited to recognized specialists.

The fact that streptomycin has made medical history in being the first antibacterial drug sufficiently harmless to the body to be usable in doses adequate to attack the infecting tubercle bacillus, has stimulated world-wide search for new and even better remedies in tuberculosis. Various new synthetics and antibiotics with powerful effects against the bacillus in the test-tube, and even in experimental infection in animals, have recently been described, but only one, *para*-aminosalicylic acid (known as PAS), has been found with sufficiently low toxicity to justify extensive trial in human pulmonary tuberculosis; such trials are still in progress. Undoubtedly research will go on, but whether it will lead to further successes remains to be seen. Streptomycin has set a high standard.

Reports just published tell of preliminary clinical trials in America of dihydrostreptomycin, a hydrogenation product of streptomycin made in the laboratory from that antibiotic. Results suggest that it is as efficacious against tuberculosis, weight for weight, but significantly less toxic.

The Restless Wind

PROFESSOR O. G. SUTTON

'A BOY'S will is the wind's will' said Longfellow, and the 'fickle breeze' has served poets well in all ages and will doubtless continue to do so. It is a commonplace fact that the air we breathe comes to us not in a smooth and orderly flow, but in gusts and lulls, and with every evidence of complete disorder. In technical, but not necessarily more precise language, the wind is *turbulent*. This may seem at first to be an interesting but not particularly significant fact, a sort of curiosity of meteorology, but it is hardly too much to say that if this were not so, living things would have had to assume shapes very different from those we now know. The restlessness of the wind is, in fact, a matter of the greatest, even of vital, importance to everyone, as will be seen later. In meteorological science it is fundamental, so much so that in the last few decades there has come to the fore the special study of atmospheric turbulence, not only because meteorology could hardly go ahead without it, but also because of the ever-growing problems of an industrial civilization.

The story of the study of atmospheric turbulence really begins just before the first world war when G. I. Taylor* took part in the cruise of the *Scotia* to investigate meteorological conditions in the North Atlantic in general, and the cause of fogs in particular, an expedition prompted by the disaster to the *Titanic*. In 1915 Taylor published in the *Philosophical Transactions* of the Royal Society some results of his work in what has since come to be regarded as the classic contribution on the subject. About the same time

*Now Sir Geoffrey Taylor, F.R.S., Yarrow Professor at the University of Cambridge.

another English mathematician, Dr L. F. Richardson, took up the study of turbulence in the lower atmosphere, while on the Continent the Austrian meteorologist, Wilhelm Schmidt, began to make it his life's work. Before this, Osborne Reynolds had made clear the nature and principal effects of turbulent motion in his famous experiments on the flow of water in long straight pipes, but the detailed study of atmospheric turbulence really begins with Taylor, Richardson and Schmidt.

The problem of atmospheric turbulence is the problem of *large scale mixing*. If we have a volume of gas (such as air) 'at rest' at normal temperatures we know that, although there is no movement of the gas as a whole, the molecules which compose it are rushing about in all directions at high speeds. In doing so they collide with each other and, to a first approximation at least, we may consider that these collisions are very like those which take place between elastic spheres, such as billiard balls. If now, one layer of the gas starts moving as a whole in a definite direction, the effect of the incessant motion of the molecules which compose it will be to set other molecules, not in the layer and initially devoid of orderly motion, also moving in the same direction. That is, the orderly motion which was initially confined to one layer of the gas spreads throughout the whole gas, owing to the random motion of the molecules. This effect is called *viscosity*. In the same way, if one part of the gas becomes hotter than the rest, that is, if the molecules in that part acquire an enhanced energy of motion, the collisions which take place with other molecules mean that this extra energy is shared with all the molecules, or that heat is *conducted* through the gas. Finally, if particles of smoke or molecules of another gas, such as water vapour, are introduced into the air, the random motion of the molecules means that in due time the foreign matter *diffuses* throughout the entire volume. A discrete particle is bombarded on all sides by the molecules of the gas in which it is floating, and these pushes make it take an exceedingly

irregular path. Such movement of small particles, due to the random motion of the molecules, is called Brownian motion, and constitutes one of the most vivid pieces of evidence of the truth of the molecular theory.

These facts are now among the commonplaces of Natural Science. They have one outstanding feature, the extreme slowness of this sort of mixing, due to the fact that although the random motion of the molecules is always very rapid, it is also very local in its action. In the phraseology of the kinetic theory of gases the 'mean free path', or the average distance travelled by a molecule between successive collisions, is extremely small at normal pressures. Air at rest, for example, is a very poor conductor of heat. An eiderdown quilt keeps one warm in bed simply because the air trapped between the tiny feathers cannot easily move and therefore can only conduct heat away from the warm body to the cold outside air by molecular action, and this is very slow.

On the other hand it is obvious that it is extremely easy to mix up gases rapidly and efficiently – the smoke-laden air of a room is very quickly changed by churning it with a fan. This is a fortunate fact, for if molecular action were the only means of getting the atmosphere mixed we should be in a bad way. Even quite small towns would quickly become uninhabitable because of the accumulation of foul air near the ground, heat would take a very long time to pass from the ground into the air above, and evaporation (and hence the replenishment of the water vapour of the atmosphere) would be a slow and inefficient process. The climate of the earth would certainly be utterly different from what it is like now, most probably one of extremes, and it is difficult to envisage with any confidence what a world which relied entirely on molecular mixing would be like. Weather is due to inequalities of pressure, heat and water vapour over the globe, and it is not difficult to see why meteorology must therefore take a great deal of notice of mixing. It is also clear that the atmosphere, like the air in a room fitted with a fan, is normally mixed by the random

movements of large volumes of air, rather than of individual molecules, from one level to another. Such irregular motions constitute the turbulence of the wind, and it is the theory of these motions and their effects which is the principal aim of the study of atmospheric turbulence. Turbulence thus appears to the meteorologist as the great natural means of mixing, chiefly responsible for the distribution of the heat received from the sun,*, the spread of moisture in the form of vapour, the cleansing of the air from pollution and many other effects, not all meteorological in their ultimate significance.

The kinetic theory of gases achieves a remarkable triumph in that, starting from the somewhat crude mechanical concept of the random motion of 'billiard ball molecules', it is able to predict the chief physical properties of gases and in particular their viscosity, conductivity and diffusivity. The question which confronted the early workers in atmospheric turbulence was as follows: the large-scale mixing which is so clearly manifest in turbulent motion can be thought of as arising from the random motion of relatively large masses of air, called *eddies*, which break away from the mean orderly flow to carry momentum, heat and foreign matter from one level of the atmosphere to another. In this sense, therefore, the eddies are the macroscopic counterparts of the microscopic molecules. Is it possible to build up a kind of kinetic theory of eddies and so to predict in advance the rate at which the turbulence spreads momentum, heat and mass throughout the air? If so, one of the basic problems of meteorology would be solved.

The analogy between molecules and eddies is very attractive, but several difficulties immediately appear. In the kinetic theory of gases molecules are permanent bodies which are supposed to have many of the properties of

*The direct radiation from the sun is chiefly of short wave-length, which passes through the atmosphere with little absorption. Its main effect is to heat the ground or the sea and thence, chiefly by turbulence and partly by conduction and long wave radiation, the air above.

elastic spheres. Clearly, nothing quite like enormous billiard balls can be imagined floating in the wind, and nothing as simple as 'collisions' can take place between eddies. The eddies in the wind are regions of concentrated spinning motion, or vorticity, caused chiefly by the friction of the ground; the wake which streams away behind a body moving through the air is mainly composed of such patches of rotating air, the broken-up remains of the boundary layer of the body. As the eddies float away in the wind they grow larger and less intense and are ultimately reabsorbed into the main motion by the attrition of viscosity. The molecules of a gas are all of the same size, whereas an inspection of the record of a sensitive anemometer placed near the surface of the earth shows that the oscillations caused by the passage of the eddies are of periods varying from a fraction of a second to many minutes, with no semblance of regularity. This can only mean that eddies in the natural wind have 'diameters' varying from a few centimetres to hundreds and even thousands of metres.

It is obvious that any attempt to formulate a precise and detailed mathematical description of the confused mass of whorls which make up the wind is doomed to failure, but it is possible to make considerable progress if the details are ignored and attention concentrated on the integrated effect. This is exactly what is done in the mathematical treatment of molecular action. Brownian motion, for example, reveals a particularly jumbled pattern of random movements when the tracks of single particles are followed, but considered as a whole, it is possible to predict the mass effect with considerable accuracy, as Einstein showed. In other words, any theory of turbulence must necessarily be *statistical* in its approach; just as an insurance company remains solvent by ignoring individual cases and considering the population as a whole in fixing its premiums, so must the mathematician be content with a broad view of the phenomenon of turbulence if he is to make progress at all.

The initial attempts to produce a workable basis for calculation were, naturally, founded on a considerable simplification of the problem. It was assumed that the integrated effect of the random motion of the eddies is to produce a kind of magnified viscosity, conductivity and diffusivity, analogous to the molecular counterparts in that the macroscopic coefficients were supposed to be constant, and thus to have the same value at all positions in the field. This is much the same as assuming that the eddies are all about the same size. Taylor defined in this way a quantity called the *eddy viscosity*, K, corresponding to the familiar kinematic viscosity of the molecular theory, while Schmidt employed for the same purpose a similar quantity called the *interchange coefficient* (*Austauschkoeffizient*) A, corresponding to the dynamic viscosity. These two quantities are related by

$$K = A/P \ [rho]$$

where P is the density of the air. Thus K is measured in square centimetres per second, A in grams per second per centimetre, and clearly K is numerically nearly a thousand times greater than A. Most English meteorologists have remained faithful to K, while nearly all continental writers use A; this, of course, is purely a matter of taste. There are many ways in which these quantities can be calculated. Taylor used the results of meteorological pilot-balloon ascents to determine K from the way in which the speed and direction of the wind changes with height as a result of the frictional drag of the earth's surface, and he also used the variation of air temperature with height to evaluate the *eddy-conductivity*, that is, the value of K for heat transfer. Schmidt, with true Teutonic thoroughness, examined a much wider range of phenomena in order to obtain representative values of A. He collected data for the variation of wind with height, for the change of the time of maximum temperature over the 1,000 feet or so of the Eiffel Tower in

Paris*, from observations on drifting snowflakes, from the way in which the air grows drier as one ascends, from the travel of smoke, the scattering of pollen and the dispersion of radium emanation from the ground and so on, and found support for the hypothesis, first advanced by Taylor, that all these varied phenomena give rise to macroscopic coefficients of viscosity, heat conduction and diffusion of the same order of magnitude and which are therefore, in all probability, equal. The most striking result was undoubtedly the magnitude of K thus revealed – about a hundred thousand times greater than the corresponding molecular coefficient. In other words, molecular mixing is utterly insignificant compared with turbulent mixing.

At this stage it must have seemed to most meteorologists that, by an unexpected stroke of luck, the turbulence problem had proved less intractable than had been expected. If the diffusing power of the atmosphere could be specified with reasonable accuracy by a single coefficient whose magnitude was easily established, all would be well. The investigations of Richardson, however, soon dispelled this hope. Richardson devoted a good deal of attention to phenomena of widely different magnitudes, starting with the scattering of smoke or thistledown over distances of the order of a few hundred yards and ending up with diffusion over enormous distances, up to several hundred miles, using for the last-named data from balloon races and measurements of the deposition of dust from volcanic eruptions. He found that K varied enormously with the scale of the phenomena. For short range diffusion, K lay between one hundred and one thousand cm^2/sec, but for the really large-scale processes values as high as 10^8 or even 10^{11} cm^2/sec. were necessary to account for the observations.

One meaning of this result is obvious. The approxima-

*At about 4 feet above the ground the air temperature reaches its maximum at about 2.30 p.m. G.M.T. in southern England. At a height of about 1,000 feet it does not attain its maximum until about 9 p.m. G.M.T.

tion K=constant, which had proved so useful in the initial investigations, could no longer be regarded as adequate for more exact and detailed work. There is, of course, nothing surprising in this, for the atmosphere is anything but uniform in structure. The degree of turbulence shown by the air decreases rapidly with height and practically vanishes above 2,000 feet, and it is also clear that K must depend, in some complicated way, on such factors as the strength of the wind and the irregularities of the terrain over which the air is passing. What is remarkable and encouraging is that so much valuable information can be gained from such a simple initial hypothesis. The difficulty now was to envisage the next step.

This came from aerodynamics, in which turbulence is likewise a matter of prime importance. Measurements in wind tunnels are naturally far more exact than any which can be made in the open air, and a theory of considerable precision is needed here. Since the days of Osborne Reynolds, numerous attempts had been made by eminent mathematicians to solve the basic problem – how and when laminar flow breaks down into turbulence – but with only partial success. The completely rational and exact approach seemed – and still seems – hopeless. Aerodynamics needed some not too involved theory which would enable it to reduce to order the seeming chaos which appears in problems of turbulent flow on the laboratory scale. The famous German mathematician Ludwig Prandtl, well known for his classical work on boundary layer theory and on the vortex systems of aerofoils, provided an answer with one of those simple but powerful ideas which are the true mark of genius.

In the kinetic theory of gases the concept of the mean free path is fundamental. Thus the kinematic viscosity of a gas is proportional to the mean value of the product of the molecular velocity and the length of the free path. Prandtl suggested that there must be a similar length, playing an equally fundamental rôle, in turbulent motion. Imagine an eddy, conceived as a relatively small volume of fluid, break-

ing away in some manner from its surroundings and drifting to another level. It will carry with it a content of momentum, heat and foreign matter typical of the layer from which it originated, and when it arrives at the end of its journey it will mix with the air at the new level, giving rise to an instantaneous fluctuation of velocity, temperature or concentration of foreign matter. The distance which the eddy travels before it disappears again into the main motion of the air Prandtl called the 'mixing length' (*Mischungsweg*), and by extremely simple mathematics he was able to show that the coefficient K could in this way be expressed as the product of the square of the mixing length multiplied by the velocity gradient or rate of change of velocity with distance from the surface.*

This very simple idea provides a means of analysing phenomena in turbulent flow without the necessity of inquiring, at this stage, whether the physical picture which lies behind it is true or not. (In fact, it is probably anything but true.) The success of the concept is primarily due to the fact that the length l thus introduced turns out to be virtually independent of such factors as the viscosity of the air, or the mean speed of the flow, and in an astonishingly wide range of phenomena the simple expression $l=kz$, where z is distance from the boundary and k is a constant, suffices to explain most of the features of turbulent flow near solid bodies. The number k is known as Kármán's constant, and for aerodynamical applications the value $k=0.4$ has been found to be appropriate. Kármán's constant is the nearest approach to a true universal constant yet found in fluid motion. Recently, P. A. Sheppard deduced the value of the constant for the atmosphere by measuring, most ingeniously, the frictional drag of the ground, and it is a matter of considerable interest that the values he obtained for k are

*in mathematical symbols, $K=l^2\dfrac{du}{dz}$, where l = mixing length, u = average speed of the wind, z = distance from the surface.

extremely close to those found in the laboratory. This is an amazing result when the enormous difference in scale between the two phenomena is realised.

The Prandtl analysis is not altogether convincing to a mathematician, and in 1932 Sir Geoffrey Taylor took up his 1915 theory again and expanded it into the so-called 'vorticity-transport theory'. Prandtl had assumed that the eddy carries its content of momentum unchanged from one level to another, but from the aspect of exact hydrodynamical theory, this is questionable. Taylor was able to show that there are grounds for believing that the entity which is transported unchanged is vorticity, or spin, although the ultimate result is the transfer of a certain amount of momentum. Both theories have their strong and weak points, and at the present time it is difficult to say which is regarded with the greater favour by workers in aerodynamics. Taylor's theory is probably more exact but is undoubtedly difficult to apply; Prandtl's theory is more intuitive and considerably easier to employ, but does not appeal as powerfully to the mathematician, because of its lack of rigour.

There is another way of approaching turbulence, and to follow this we must go back to 1922, when Sir Geoffrey Taylor broke new ground in the pages of the *Proceedings* of the London Mathematical Society with the theory of 'Diffusion by Continuous Movements'. There is a famous (and quite serious) problem in pure mathematics known as 'The Drunkard's Walk'. Imagine an inebriated citizen starting to walk from point *A* to point *B*. He will take a number of steps, all vaguely directed towards *B*, but, if he has reached the ultimate state of his kind, there will be no connection between any step and those which precede and follow it. He is quite as likely to step sideways or even backwards as much as he is likely to go forwards, and his position in the road at any instant can only be described in terms of probabilities. The problem of the drunkard's walk is to determine this probability. A particle of smoke floating in a turbulent stream may be likened to the citizen; the

eddies which buffet it about carry it in all directions and its ultimate fate can only be assessed in probabilities.

In the problem of the drunkard's walk the steps are discrete and (in technical terms) uncorrelated with each other. Taylor studied the extended problem in which there is a variable correlation between such events, and finally the case in which the steps are not discrete, but continuous, and discovered a remarkable theorem which relates the scatter of a group of particles to the degree of correlation between the motions at successive instants of time. This is the genesis of the so-called 'Statistical Theory of Turbulence'. In 1935 Taylor considerably extended the theory, and it is perhaps not too much to say that this approach is regarded to-day as the most promising yet evolved. The application of this theory to the problems of atmospheric turbulence was, however, not made until 1932.

Practical Importance

When the Germans introduced gas attacks in 1916 they compelled an examination of the means of defence against this type of warfare, and in 1921 the Chemical Defence Experimental Station was set up at Porton on Salisbury Plain to study such problems. It is evident that one of the subjects which urgently needed investigating was atmospheric diffusion, and the present Director of the Meteorological Office, Sir Nelson Johnson, was responsible for the initial work at Porton on this subject. The resources of a Government Department meant that large-scale diffusion could be studied with a precision hitherto impossible, and for the first time the whole subject of atmospheric turbulence began to be investigated in detail. It soon became evident that the problem was even more intricate than had been thought, owing to the effects of *temperature gradient*. This is a term which needs a little explanation.

Imagine a clear day in summer. As the sun rises, the incoming radiation warms the ground, which in turn warms the air immediately above. This means that the temperature

of the air decreases with height, forming what meteorologists call *lapse conditions*. The lapse-rate, or rate of fall of temperature with height, continues to increase as the sun ascends, and it reaches a maximum about noon, after which the gradient grows less until, about an hour before sunset, the ground is losing heat so rapidly (chiefly because it is radiating to space) that the lapse-rate becomes zero. The air is then approximately at the same temperature as the ground. As night falls, the ground grows colder much more rapidly than the air, which means that the air in contact with the ground is chilled, and the state is soon reached in which the temperature of the air increases with height, forming what meteorologists call an *inversion*. If the sky is clear, the inversion persists throughout the night, and only disappears and gives place to lapse conditions when the sun rises again. All this has a profound effect on atmospheric turbulence. When a lapse rate exists, the warm air lies below cooler and therefore denser air. Because of this difference in density little bubbles of warm air start to rise, forming vertical currents, and any slight disturbances in the wind, say those caused by obstacles on the ground, are likely to persist or even grow stronger. On a clear day in summer the turbulence of the wind in the surface layers reaches a maximum in the hours around noon, for this

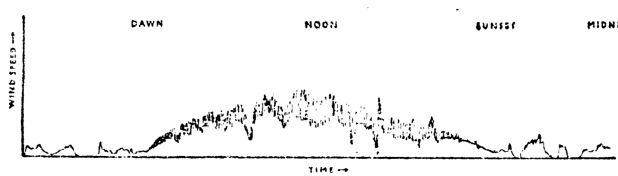

Fig. 7. – The variation in the turbulence of the wind on a clear day in summer.

reason (Fig. 7). The inversion state, on the other hand, means that colder and therefore denser air is lying below warmer air, a state of great stability, in which any disturbance is likely to be damped out. On a clear night the inversion is

often strong enough to kill the turbulence of the surface wind completely – the best time for gas attacks, in fact, is just before dawn in clear weather because it is then that the diffusing power of the air is least.

The reader can easily convince himself of the truth of this if he will observe a weed fire in the country. In the middle of a warm day in summer the smoke from such a fire is scattered over a wide arc by the turbulence in the wind, but on a clear evening the same fire will produce a thin dense plume or sheet of smoke which drifts over fields and meadows for very great distances without appreciable mixing. The moral is that if you must burn weeds in your garden, the best time to do it is in the middle of a hot windy day. Your neighbours will then suffer least.

To return to chemical warfare, it is obvious that the detailed study of the effect of temperature gradient on diffusion is difficult not only mathematically but also experimentally. In fact, the problem has not yet been satisfactorily solved. An approximate solution was found by the present writer, when a member of the Porton team, by adapting Taylor's 'diffusion by continuous movements' theory to the atmospheric case. What was done, in effect, was to assume that the correlation coefficient between the movements of the particles of smoke at successive instants decayed to zero with increasing time (like a drunkard becoming more and more intoxicated as he goes on his way), thus expressing the fact that as the smoke drifts downwind it always encounters new eddies. The mathematical analysis showed that the rate of decay of the correlation coefficient could be deduced from measurements of the rate at which the wind-speed increases with height above the ground, and once this is known, it is possible to calculate not only the rate of growth of a smoke cloud, such as that emitted by a factory chimney, but also the rate of evaporation from a saturated surface exposed to the wind, for this is simply the problem of the diffusion of he vapour cloud formed by the evaporating liquid, and

therefore differs from that of the factory chimney only in what a mathematician calls the 'boundary conditions'.

It should be clear to the reader by this time why the study of atmospheric turbulence is a matter of deep concern to the meteorologist, but this alone hardly justifies some of the statements made earlier concerning its importance to the ordinary citizen. Two actual examples may help in this respect.

During the first five days of December, 1930, a thick fog covered a large part of Belgium and in particular the valley of the Meuse, between Liège and Huy. Suddenly, in this densely populated industrial district, the doctors started to be busy. Large numbers of people were taken ill with respiratory troubles, and between December 4 and 5 no less than 63 people died, after only a few hours of sickness. On December 6 the fog disappeared and with it the mysterious epidemic. Naturally, there was a public outcry, so much so that the Belgian Government opened an official inquiry in which experts from Liège University took a prominent part. The result of this inquiry may now be read by anyone in the pages of the *Transactions* of the Faraday Society for 1936, and they may be summarized as follows. The medical evidence, based on autopsies followed by histological examinations, made it clear that the victims had inhaled noxious products in their last hours of life and that the pollution had produced local superficial irritation of the mucous membrane of the respiratory ducts. Microscopical examinations of sections of the lungs showed that fine particles of soot had also been inhaled. There was no chemical evidence of the nature of the pollution in the valley during the fatal five days, but equally, there is not the slightest reason to believe that anything but normal industrial by-products were present. Many of these, of course, are toxic or irritant, but only in high concentrations. The inquiry made it clear that the most probable cause of the deaths was industrial pollution, which during this period must have reached a dangerous level.

The real secret of the Liège disaster undoubtedly lay in the meteorological conditions prevalent at the time. There was a not very unusual combination of circumstances – an anticyclone gave low winds, and an inversion of temperature gradient was maintained a few hundred feet above the floor of the valley, – but these conditions persisted, which meant that during these five days turbulence practically ceased in that part of the Meuse valley. The prevailing pressure system caused the smoke and industrial fumes from the Liège factories to drift into the valley, which now became virtually a closed chamber, with the inversion forming a 'lid'. The result was that people who all their lives had breathed industrial gases in low concentration without any noticeable ill-effects were suddenly exposed, in the middle of winter, to higher concentrations of these gases. They died, because during those few days the natural ventilation system of the atmosphere ceased to work.

The second example is interesting because it shows how meteorological research, properly applied, can mitigate the ill effects of industrialization. At Trail, in southern British Columbia, there is the largest lead- and zinc-smelting plant in the world. In the process of extracting the metals from the ores sulphur dioxide is formed and allowed to escape from the high chimneys. Sulphur dioxide is an unpleasant gas, which not only causes violent coughing if breathed in sufficient concentration but also has a very bad effect on plants of all kinds. This gas, blown southwards over the International Boundary, has frequently caused damage to crops in the neighbouring state of Washington, thereby giving rise to a great deal of international litigation. In 1928 the assessment of the damage was taken over by an International Joint Commission (U.S.A. and Canada); the Commission reported in 1932 that to date the total damage amounted to $350,000. In 1935 an Arbitral Tribunal was created, which by 1938 decided that the ill effects could probably be reduced if a form of meteorological control were adopted. A full account of the investigations which

ultimately resulted in such a control being applied is given in a paper by Dr E. W. Hewson in the *Quarterly Journal* of the Royal Meteorological Society for July – October, 1945. In brief, the control measures prescribed by the Arbitral Tribunal are based almost entirely on observations of the wind speed and direction and on turbulence, the last named being measured by a special instrument mounted on the chimney stack. This instrument is essentially a light horizontal wheel, around the outer edge of which are a number of equally spaced blades or cups, which offer resistance to the wind. Unlike the ordinary paddle-wheel, however, this wheel is not allowed to rotate freely, but is 'bridled', so that in a fluctuating wind the wheel oscillates and thus shows not only the average speed of the wind by the average amount of the deflection, but also the amount of turbulence present in terms of the number of oscillations shown in any period. In practice the frequency of the gusts is measured in terms of deflections per half-hour – if this number is below a certain recommended minimum, the turbulence in the air is deemed to have fallen to such a low level that it is necessary to reduce the emission of the noxious fumes to save the crops.

Atmospheric pollution is part of the price which has to be paid for industrialization and national solvency, but the toll levied on health and general well-being need not be as high as it is at present. For many years the Department of Scientific and Industrial Research has maintained a close watch on the situation and has lately published an illuminating booklet *Atmospheric Pollution in Leicester – a Scientific Survey*. No one who reads that booklet will be left in any doubt concerning the importance of turbulence in the daily life of a great city. In the future it is likely that even greater care will have to be taken to see that toxic products do not accumulate at breathing level, so that the study of atmospheric turbulence is not only a delight of the mathematically minded meteorologist, but a potent factor in the health of us all.

Introduction to Sewage

SEWAGE? surely a subject that is either dull or indecent, you may say; something to do with rats and hidden pipes, and the pulling of lavatory chains? In actual fact there is a good deal more to it than that, a special variety of engineering, some specialised chemistry, and an implicit sociology. The problem is set by the human custom of living together in cities, which like all historic steps has brought endless new complications in its train.

Wherever a house is built or a road put down the rain water no longer takes its natural course and soaks into the earth to feed small streams which will later reach a river. If drainpipes are not laid, the water will collect in pools on the impermeable macadam and below sloping roofs, and small floods will aggregate. Thus one function of sewers is to drain away rainwater, and keep the city dry.*

In the past factories were small: if the washings of a tanner's yard or brewer's vat were emptied into a stream, no great harm was done. But to-day a brewery is often on a vast scale, and many new industries, oil and chemical works, have grown up, along with multiple dairies and jam factories – and all have washings, and waste to discharge from their various manufactures. If they tipped them directly into some river, supposing one conveniently near, all the fish and plant life would be destroyed, and loathsome smells would wash through all the villages downstream. To-day effluents must be cleansed and controlled, and the sewage farm helps in this task.

It is the same with domestic waste. When the scale is small, a few scattered houses, a village, there is plenty of space to bury human excreta in earth closets, to pour away

*Surface water sewers empty direct into streams or rivers; foul water sewers run to the sewage farm.

bath-water and empty kitchen sinks into a soakage pit or a stream. But multiply this by a million or so, on the scale of London, and at once it is obvious that these methods can never be other than small-scale; the area of ground is not available, the human concentration is too great. City living compels the invention of sewers to lead the waste away from each house, and sewage plant to break that waste up so that it may be safely emptied into some river. It is a matter of increasing size; the larger the social group, the more complicated becomes its organization, and the devices for its survival.

All the drainage from home and factory, and much from the roads, then, sweeps down into the single channel of the sewage farm. There it will be sorted and biologically processed. The large floating solids are filtered off and ground to shreds, the stones and gravel allowed to settle out at the bottom of long tanks, and the fine floating solid matter, fats and soaps, are acted on and digested by aerobic bacteria, and the insoluble residue allowed to settle out as sludge. The water is then clean and pure. In the most modern plants, the sludge is separated and fermented with other bacteria which produce from it inflammable gas, which can be used for lighting and heating, and to drive dynamos and cars. Still, after this, there will be a sludge residue, and when dried it becomes a valuable agricultural fertiliser. The sewage farm has become a factory in its own right. During the 1939-45 war, its inflammable methane gas, dissolved in petrol, became terrible incendiary bombs to rain down on the enemy – a further industrial by-product of its functioning.

A brief description of an actual sewage plant will illustrate the complexities of everyday operation. Mogden, of the West Middlesex main drainage scheme, is probably one of the largest and most modern plants in the world, draining the western suburbs of London, the greater part of the County of Middlesex, an area of 162 square miles with a population of more than one and a quarter million souls. Nearly all the rain falling in these 162 square miles finds

itself flowing into the sewers bound for Mogden, and naturally as the country has its hills and valleys, not all the sewers flow at the same level. In fact, roughly, one quarter of the total flow arrives at Mogden about fifty feet below ground level, and has to be pumped to the surface to join the rest. Normally, in fine dry weather 60 million gallons of dirty water pass through Mogden in the twenty-four hours. But on a stormy day, the volume mounts rapidly to 250 million gallons or more, the increase being all rainwater off the roofs and streets.

The need for constant pumping, and for variable pumping to meet a variable inflow, determines the nature of the first part of the sewage plant. In a central hall, flow-meters show graphically the rate of flow in the incoming waters, and how the pumps are coping with them. A sudden rise in the inked line is a sign of a rainstorm in the area, and the need for throwing in more pumps to the work if flooding is to be avoided. Mogden has two sets of pumps (see Plate 30). The one lot, electrically run from dynamos powered by gas from the sewage sludge, handles the routine dry weather flow adjusting its degree of pumping automatically to the flow that reaches it. (Of course, it varies throughout the day, being least at night; and even from day to day, dropping when people leave town for summer holidays, for instance). The second lot of pumps is diesel-driven, and hand-controlled, being started only to pump the stormwaters, and stopped once the weather is fine again and the flood abated.

Along with the water engineering of the pumphouse and the flowmeters comes the first laboratory work, routine chemical analyses of what is flowing in. The amount of organic matter, excreted nitrogenous matter (urine and faeces) must be known, and chemical waste, oil and so forth, from factories watched for. New or unusual substances may wreck the bacterial action of the sludge, or raise difficulties in the various sewage processes. Ordinary soaps, for instance, cause little trouble, since they are made of digestible animal and vegetable fats, whereas the new

synthetic detergents, often more powerful than the old soaps, are not susceptible to this simple bacterial attack, and are a problem to the sewage chemists. Cyanide from electro-plating works, if present in high concentration, will kill the sludge bacteria.

The first treatment of the combined flows is a filtration. Two grids, one with iron bars at four-inch spacings, the other with three-quarter-inch gaps, separate off the paper, sticks, rags and so forth carried along in the stream. Periodically, electrically-driven rakes clean the filters and pass the dirt to a belt conveyor which carries it away to a disintegrator whence it will emerge fragmented into tiny particles, to be thrown back into the flow and thence again through the filters.

The second treatment is to guide the flow through long grit chambers. Here the gravel and other heavy stuff washed down in the sewer stream is allowed to settle out to the bottom as the flow slackens. From there it can be sucked up and carried away in special pipes. After washing with clean river water, and drying two or three days in the open air, it is ordinary sand.

Now the flow passes the stormwater weir. This is an emergency switch. When the flow rises rapidly after a cloud burst, taps are automatically closed to prevent the sudden great flood of diluted sewage washing through the processing tanks, and instead it is shunted into special large stormwater sedimentation tanks to await a dry spell, when it can be gradually added back to the main flow, or if it really is nothing more than rainwater, led straight into the river. Thus the sedimentation and sludge chambers are protected against disorganization.

The third treatment is a sedimentation: the finer particles suspended in the water are allowed to settle slowly out under the slow, calm conditions of the tanks. The sewage spends a total of six hours in the primary and secondary tanks, which have gently sloping walls, and power-driven scrapers which gradually brush the accumulating sediment or sludge to the

outlet at the bottom. From there it is pumped off to the raw sludge station. This simple technique, by scrupulous control of details, reduces the suspended solids by four-fifths to about seven parts per hundred thousand, cutting the total impurities by approximately half. Scrupulous control of details means laboratory analyses. Sedimentation can be easily upset. Suppose a brewery has discharged some yeast; suppose the weather is warm; the yeast, sedimenting out with other organic matter at the tank bottom, begins to ferment it, producing bubbles of gas which push up towards the surface – and destroy the orderly sedimentation.

The fourth treatment is the most recent innovation, and was first thought of in 1913. It is the addition of *activated* sludge. If at this stage sewage were merely allowed to stagnate, the various microbes it already contains would in time ferment it to various fresh and simpler products. Part would become gas, like the marsh gas which sometimes slowly bubbles up from decaying vegetation. Some of the organic nitrogen compounds would become ammonia, and nitrates. But there are only a few bacteria, clinging mostly to the suspended particles, in ordinary sewage, which is too dilute in microbes therefore to ferment very quickly, If it had to be purified spontaneously, it would take days. The activated sludge process consists therefore in enriching the sewage with millions of millions more bacteria, which between them can do the job quickly, in a matter of hours. These microbes are prepared by taking ordinary sedimented sludge (from the previous stage) and blowing air through it. The bacteria are oxygen-loving, and thrive on the additional air, and they grow better if warmed to their optimum temperature.

This activated sludge is prepared in a special station, where numerous samples of test of its activity are frequently taken: density, colour, if necessary, microscopic examination. From here it is fed into the aeration tanks which also receive the sewage passing on from the sedimentation stage, and the two are mixed together by blowing compressed air

through them (see Plate 31). The sewage has to travel a distance of about 1,600 feet in all in the aeration unit, and is fermented by the bacteria for about seven hours. At the end of this time it passes into the final sedimentation tanks, where the added sludge settles out again, together with that previously carried along in the sewage. This sedimented sludge will be pumped back in part to make more activated sludge, so that once this part of the process is started it runs in a circle and is self-supporting. The surplus sludge (920,000 gallons of it on an ordinary working day) undergoes a two-stage digestion, i.e. further fermentation under different conditions. The sewage itself, after the final sedimentation, still contains suspended solids, but now only to the extent of 0.7 parts per 100,000, and its nitrogen is in the harmless form of nitrites and nitrates. It is perfectly clean and safe and is emptied into the River Thames.

The digestion of surplus sludge at Mogden yields over a million cubic feet of gas a day, a gas which is 70 per cent methane and 30 per cent carbon dioxide and which is used for heating, for providing the power for nearly all the pumping machinery, and for driving the 'factory's' vehicles. It is estimated that over an eleven-year period they have saved the importation of nearly 13 million gallons of fuel oil, which would have been required to drive all the machinery if gas had not been available. The gas production is carried out in special enclosed tanks, heated to 85°F. and maintained at an alkaline pH. The process continues for 24 days, when half the solids have been decomposed.

At the end, the sludge residue is pumped away to open-air drying beds, which cover 70 acres or so of land. Here it packs down to a cake finally about 4 inches thick, and still containing nearly fifty per cent of water, and it can now be shovelled and shifted in trucks. The 40,000 tons annual output of sludge cake is bought by farmers as a valuable fertiliser, and agricultural demand now exceeds the supply.

In this brief account it is not possible to describe the pumping machinery, the flow meters, and the control of the

processes by analytical chemists at all stages. Nor is there space to detail the commercial considerations of management and costing, which ensure that the right number of trained men (about 140 in all) are available to do the work, and that the processes run are not a heavy burden on the rates.

A vigilant watch has to be kept by the management both on the work they will be called on to do, and on the conditions in the River Thames. There have been times when half the total flow of the Thames downstream from Kew has been sewage effluent from Mogden, and it says a great deal for the processes and their control that this has been safe. The area the sewage works serves continues to acquire new industries, some with strange chemicals, others (like the building of London Airport) merely increasing the water flow. More houses are built too, and so the domestic sewage output rises. People's habits change – rationing, for instance, has been found to alter the chemical nature of the sewage very perceptibly. The weather may change, and so meteorological forecasts become important. Always the works must keep a jump ahead, with sufficient capacity to take what comes, with sufficient tricks of adjustment to pamper the sensitive fermenting bacteria and keep them cooperating. For in the end, the possibility of modern industrial and urban life depends on the empirical use of these microscopic living plants. We commonly think of bacteria as the germs of disease. It is worth remembering that in fact the pathogens are a small minority, and amongst the ninety per cent of harmless organisms, the aerobic bacteria of Mogden must occupy an honourable place.

Life in Graham Land

DR A. R. C. BUTSON

I HAVE just returned to England after a period of eighteen months spent as medical officer to the Falkland Islands Dependencies Survey in the Antarctic, the base to which I was sent being in Marguerite Bay, Graham Land (see Plate 7).

Graham Land is that peninsula of the Antarctic continent that runs up towards the southern tip of South America. This peninsula is of a highly mountainous nature, and is, in fact, a continuation in the Antarctic of the Andes range, some of the peaks reaching as high as 13,000 feet, though the general height is of the order of 5,000 to 6,000 feet. On the west, or Pacific side, of this peninsula is the Bellinghausen Sea, a sea which is mostly free of sea-ice in the summer. On this western side of Graham Land lies a delightful archipelago of islands, mainly mountainous and separated from each other and from the mainland by sea channels and straits.

Snow accumulates on the mountainous plateau mainland of Graham Land, forming a layer of highland ice about 300 feet thick, and this ice tends to flow down the valleys as glaciers. On the west coast these glaciers debouch into the Bellinghausen Sea and 'calve' off icebergs, some even seven miles long.

On the east or Atlantic side of Graham Land lies the vast bight called the Weddell Sea, a sea filled with pack-ice during most of the year. Skirting this coastline of Graham Land is a belt of 'shelf-ice' extending fifty to one hundred miles into the Weddell Sea. Shelf-ice is sea-ice that has accumulated over centuries until it has attained a depth of as much as 800 feet, of which only 150 feet will be floating

above the water level. This shelf-ice is crevassed like a glacier, though the crevassing is most noticeable in the region of capes, glaciers and islands, or 'nunataks', as rock islands emerging from an ice-field are called.

On the east coast the glaciers merge with the shelf-ice so that it is difficult to tell where a glacier ends and shelf-ice begins.

There were ten other men at our base in Marguerite Bay, this being one of the two main survey bases of the F.I.D.S. We at Marguerite Bay were mainly busy with the work involved in a topographical survey of this country. This required sending out ground parties, travelling by dog-sledge and camping at night. Other scientific work on the expedition included geological, zoological and botanical field work, and the recording and transmission by wireless thrice daily of meteorological readings to the civilised world. We had an aeroplane to assist the sledging parties and to fly sledging rations onto the 6,000 ft. Graham Land plateau.

The F.I.D.S. is being run for several years, and each year a ship is sent out to the various bases with relief personnel, mail, stores and provisions for the year. Because of the liability of meeting broken-up sea-ice, called pack-ice, a steel vessel is unsuited for the voyage, and wooden vessels are required. The voyage for the ship is not without danger, as the waters in this area are largely uncharted, what charts are in existence being inaccurate. The sea on the west coast of Graham Land is studded with reefs rising sharply from deep waters, many islands are uncharted, and storms and fog may drive the ship against an iceberg with fatal results. A number of vessels have been caught in pack-ice off the coast of Graham Land, and either crushed or imprisoned for a year, during which time the vessel is relentlessly carried by the drift of the pack-ice for as much as a thousand miles. The power of sea-ice, several feet thick, is difficult to imagine, but our lives down South were greatly influenced by this *vis naturae*.

The passage in a small ship from Port Stanley across the Southern Ocean, even in midsummer (January) to Graham Land is rough and unpleasant, but once off the Antarctic coast the ship's passage is relatively calm. This is due to the seas being land-locked and the swell being damped by pack-ice and bergs. The voyage among the islands off the west coast of Graham Land must be amongst some of the most beautiful scenery in the world. The snowy mountains rising sheer for as much as 6,000 to 10,000 feet out of the pellucid waters, the varying shades of blue and green of the ice-cliffs, the seals basking on the floes, the tinkle of the brash-ice caused by the ripple set up by the ship's bow wave, the rush of waves breaking on an iceberg, all make up an extraordinary picture. The atmosphere on a fine day in the Antarctic is clearer probably than anywhere else in the world, mountains a hundred miles away seeming to be distant but a couple of hours' walk. It is difficult to adjust oneself to this immensity of the geographic features and to the clarity of the air.

For us members of the expedition, however, the voyage was not altogether a pleasure cruise. As soon as the ship arrived at one of the seven bases, the unloading of stores commenced immediately. At some bases the hut was built while unloading progressed. Unloading was always a rush, as one never knew when a gale would spring up, making it impossible to continue our work, or if pack-ice would drift around the ship and trap her. During this period we would do hard stevedoring work for as long as twenty hours a day. If the ship's motor boats were not in working order – and they rarely were – we had to row the stores ashore by hand, and lifting full forty-gallon drums of petrol out of a lifeboat on to an ice bank in a rough sea is no easy task.

Hut building had to be speedy, as until the walls were up and the roof on and anchored to the rock with cables, there was always some anxiety in case the hut should blow away in a strong wind. A fall of snow or drifting snow also

handicapped building operations by covering building materials and tools. All of our huts were built on a rock foundation, cemented in, but the superstructure was made entirely of wood, two layers thick, and insulated by tarred paper and aluminium foil sheeting.

Sooner or later one was left at the assigned base and said good-bye to the ship and crew. Stores had then to be carried well up the beach away from sea spray and stacked in carefully sorted piles under tarpaulins. I arrived at Marguerite Bay to a hut already built the previous year, but our first job was to build a hangar for our Auster plane. This hangar was designed and built of wood planks by seven inexperienced men in a week. Later the same number of men put up a Nissen hut as a store shed in three days. The biologist on his own built a fair-sized laboratory in five days.

There were about sixty Labrador husky dogs at Marguerite Bay when I arrived there. Most of these dogs had been brought down to the Antarctic from Labrador the previous year, and had started breeding successfully in the Antarctic. Our work and life was bound up intimately with the husky dog, and to them one must attribute most of the pleasure that we gained from our life. I do not think that there is any creature so entirely lovable as the husky dog. He is probably the most affectionate animal to man, although he is fierce in his dealings with other animals and his own kin. Naturally teeming with spirits, he revels in life among the snows, working for his lord and master. Around the base we had to keep them chained up to prevent them from fighting among themselves and killing or seriously maiming each other. For us the loss of a well trained sledge dog was a serious matter.

An adult male husky weighs 80 to 90 lb., though some reach 120 lb. They are similar in appearance to a wolf, and indeed have a slight wolf strain in them, though they are slightly smaller in general. The huskies like to keep in groups, and this makes them easy to run in teams of seven,

nine or eleven (see Plate 11). On any one team the dogs will always fight it out till one dog is the supreme or 'king' dog, and all the rest of the team will lie down to the king dog in a fight. Occasionally a group, usually brothers, will club together to form a pact and by this collective measure subdue an individually superior lone dog. In every team a dog is selected and trained to lead the way in front of the rest. He is not usually the king dog of a team, but is chosen for intelligence and sensitiveness in responding to the dog driver; he is often an aloof and lonely dog. For long distance journeys, dogs are preferable to bitches in pulling power, and, not being liable to pup while on the trail, are more desirable, so that most teams for long journeys were all dog except for one or two bitches, which are included to keep up the morale of the dogs. It is surprising what a difference one bitch will make to the pulling power of the team as a whole.

Each dog requires about 3 to 4 lb. of fresh meat every other day. We used to feed them on seal meat while at the base. In summer we would strip the skin and blubber off the seal carcasses and cut up the meat with an axe and knife; but in winter we gave the dogs skin, blubber and all, frequently cutting up the seals with cross-cut saws while they were frozen stiff. When out sledging we killed seals to feed to the dogs whenever possible, as the fresh meat provided them with vitamins; but otherwise each dog got 1 or 1¼ lb. of Bovril dog pemmican daily when sledging. This pemmican was composed of dehydrated cake rich in protein.

The husky is a scavenger, so that when hungry, as he often is when on the trail, he will eat sealskin boots, leather whips, thongs, and leather gloves, if given half a chance. When hungry, he is also a coprophil.* At any time, the sight of a penguin will drive him crazy with joy for blood sport. He enjoys attacking a seal, though once he has sated his curiosity by biting a seal several times, he will not per-

* i.e., will eat his own and others' excreta.

sist in this sport unless hungry. The seal's skin is tough, and under it is about four inches of blubber, so that the dog's teeth have little effect.

Training the dogs to run in teams, training lead dogs, and training pups, took up much of our time at the base in winter. Some pups took readily to running in a team, others would rebel and run out to one side or lie down till they were dragged along by the rest of the team. Sooner or later they came to realise that the easiest thing to do was to run with the team, and once they had got the idea into their heads they would enjoy the exercise of pulling. The Labrador husky is bred for pulling and not for speed, so that he is stocky, with broad shoulders and muscular thighs. Once they are in harness it requires a strong man to take a couple of these dogs for a walk.

We used the Labrador Eskimo words of command on the dogs, – 'wheet' to urge them on, 'owk' to turn them to the right, 'irrah' to the left, and 'aah' to stop. To control them, we used a 35 ft. long Labrador dog whip; once the dog had felt the sting of this whip in its training, one rarely needed to let him feel it again. To steer a recalcitrant leader, one had merely to throw the lash of the whip alongside the team, when they would turn away from it. All the dogs responded to their names. It was remarkable how sometimes a dog would respond to an exhortation to pull harder only when you picked up the whip, even though he had not looked round. If you did throw the whip at him and missed badly, he might turn round and laugh in a 'doggie' way. Frequently dogs would look round and smile at you in a friendly way as you skied along with the sledge at the back of the team. If one's treatment of the dogs was just, they appreciated it, and having boxed a dog's ears for some misdemeanour, such as starting a fight, he would wag his tail and lick one's face. Each team got to know the voice and personality of the dog-driver, and responded to his voice.

We used to keep the dogs out-of-doors throughout the year, and they probably stood the cold better as a result.

They seemed to notice the cold only when it was windy and when there was no soft snow under which to bury themselves. During a blizzard when snow fell with a driving wind they would lie perfectly happy and warm half buried in the snow. They used to curl up with their backs to the wind and their heads between their paws. If the blizzard persisted for several days, one might see little else than their noses which remained uncovered. On these occasions we had to be careful to dig out the dogs periodically to ensure that they had sufficient free length of tethering rope. We always envied the way the dogs were able to curl up and make themselves at home in the snow when the weather was vile, or the way they enjoyed a good roll in it on a sunny day.

Husky bitches varied greatly in their ability to rear pups under these conditions. Intelligent and conscientious bitches would do everything for their puppies; others might neglect their offspring, or maim them by clumsiness. Bitches that pupped on a sledging journey might even eat their litter. In really cold weather, we had to give the puppies much attention and keep them in a relatively warm, sheltered kennel.

We spent a lot of time in collecting seals for dog food. Unlike the Arctic seal, the Antarctic seal is tame and bigger, weighing between 500 and 900 lb. We usually shot them with a .303 service rifle, or hit them on the nose with an ice axe to stun them, then slit the throat with a sharp knife. I was constantly impressed with the seals' tenaciousness of life; they wriggled and twitched disconcertingly for up to an hour after being killed. We dragged them back to the base on or behind a sledge pulled by a dog team.

The Weddell seal, commonest in our area, pupped during the last weeks of September and the first weeks of October. During this period, one would find many seals on the sea-ice where they pup. The seal pup is a delightful furry creature, with pathetic eyes and a little cry. Seals were present throughout the year, though most numerous in summer.

Penguins were entertaining visitors for the warmer half of the year. They live in rookeries along the Antarctic shores, coming to mate and build their pebble nests in early summer. They lay their eggs, usually two, in November, and so the chance to collect fresh eggs comes but once a year to the human intruder. Penguin eggs vary in palatability according to species, the Adélie penguin egg being most palatable and similar to a goose egg (Plate 12).

Everyone is familiar with the waddling gait of the penguin; few, however, realise that this is varied while walking over snow by the penguin propelling himself along on his belly with his feet. Though clumsy on land, the speed of the penguin in water is remarkable. Here he travels with amazing speed, darting from side to side as he progresses. They have no difficulty in keeping up with a ship. Occasionally a penguin would wander in curiosity among the dogs tethered at base, and usually stop within a few inches of a dog's drooling jaws, while sixty hungry dogs howled encouragement.

During the warm half of the year, many other birds abounded; Antarctic skua gulls were common, hanging like vultures around any dead meat. Snowy, Wilson's, Silver-grey, and Giant petrels, Antarctic terns, Greater and Lesser Black-backed gulls, cormorants, and Cape pigeons are all summer visitors to Graham Land. They are nearly all remarkably tame.

The sea off the Antarctic shores is teeming with life. Our biologist fitted a dredging apparatus over a crack in the sea-ice, the amount and variety of his haul always being a source of amazement to us.

Vegetation in Graham Land is virtually limited to lichens and mosses, varying in all shades of red, brown and green. During a year fifty different species of moss and lichen were collected from the neighbourhood of the base. We did find one or two patches of coarse grass in the locality, but never covering more than a few square yards. The base hut had a small greenhouse attached, and for six months of the year

we enjoyed occasional fresh salads of lettuce, radish and cabbage, and, in addition, had the living-room brightened with flowers.

During the winter, the sun left us for three months, but there was always enough twilight to enable us to work about five hours out-of-doors. A typical winter's day would be as follows. At 7.30 in the morning the alarm goes and the cook for the week unwillingly gets up and dresses in the cold room. At 7.50 he calls everyone, but there is little sign of life till 8.00, when the porridge is served. We all slept heavily and lengthily, especially during the winter. Breakfast consists of porridge, followed by scrambled eggs and bacon, coffee or tea. After washing up, the meteorologist puts on outdoor clothes to take the 9.00 a.m. readings, and the wireless operator starts his generator after heating it with a blowlamp, and then 'goes on the air.' One man proceeds to do his fortnight's laundry in our home-made bathroom; a couple of men go into the workshop (see Plate 10) to get on with making a rear skid for the aeroplane, while the rest congregate in the warm living room reading, talking, writing, sewing dog harness or splicing traces, one man repairing his wind-proofs on the sewing machine, while the poor cook for the week pounds the dough at his task of bread-making.

At 10.30 we stop work for a cup of tea, and soon after, as it is now light enough, a surveyor and an assistant go off to continue soundings of the fiord by chipping holes in the sea-ice and letting down a lead-line. Five others are occupied in harnessing and taking out two dog-teams, each with a difficult young pup for training. Two others go out on to the sea-ice with a sledge, boxes, ice-picks and shovels, to chip off and load about half a ton of fresh ice from a small ice-berg, for melting into cooking and washing water. The business of fetching ice for water is an almost daily task. This ice is collected by the dog-teams on their return to the base from their training run. Lunch is at 1.00 p.m. and to-day consists of tomato soup, cold ham and brisket of beef,

mashed potatoes and chopped carrots, followed by a treacle pudding.

After lunch, three men take the slop bins down to the tide crack; that is the crack formed by the tide at the junction of the sea-ice and land ice. A dog team and sledge is taken out in the afternoon to collect a seal that was killed in the morning. Two men occupy themselves with the reconstruction of a sledge in the workshop.

At 3.30 in the afternoon most men foregather at the seal dump to chop up and distribute half a ton of seal meat to the dogs, those dogs which have been out for a run to-day getting an extra large share. Tea follows, and this is the meal in which the cook excels himself with a sponge-cake and home-made gingersnaps. It is dark after tea, so except for the two who go off to the hangar to finish the work on the sledge, the rest settle down to indoor activities, some typing out lists of stores that need to be brought down by next year's relief ship, others writing up diaries and reports; a surveyor gets out a map that he is working on; one man monopolises the sewing machine; another heats up the dark room and melts some fresh snow preparatory to spending an evening on photographic work.

Supper is at 7.00 p.m. and consists of steak and seal kidney pie, potatoes and green peas, followed by tinned fruit and custard, tea or coffee. After supper the gramophone is brought out and chosen records are played. Light classical music is preponderantly favoured. There is always a lot of sewing work to be done, frequently of canvas and other thick materials, so it is not surprising that one man should be making an article of sledging equipment with sailmaker's needle and thread. The bathroom is occupied by one man having his fortnightly tub.

At 10.30 p.m. the generator and main lights are switched off to conserve fuel, and by then most men are in their bunks, reading by the light of a small battery lamp or candle. By midnight all lights are out and so ends another day of the dreaded 'long winter night'.

By contrast, a typical day in summer around the base may be described. At this time of the year most men are out sledging and four only are left at the base. Immediately after breakfast the slops are dealt with, and water syphoned into the water tank from a near-by black drum in which snow has been melted by the sun's rays. The surveyor and biologist go off for the day with a few dogs and sledge across the sea-ice to a nearby island, the one to work with plane table, and the other to collect specimens of animal and vegetable life from the many thaw pools among the rocks. At this time of the year we are very sunburnt, and walk about in shirtsleeves. The two left at the base send off the meteorological reports by radio, and between reports prepare a fresh site for tethering the dogs, as the sledging parties are due soon to return. After tea-time two men go out to feed the dogs and puppies, while the other two do the office work that an official Government expedition necessitates. After supper everyone turns out for an hour's skiing, and it is well after midnight before the curtains are drawn to keep out the midnight sun, and all activity ceases.

Most of the personnel at the F.I.D.S. main base are sledging men, whether they be surveyor, geologist, handyman or doctor, and a sledging man can reckon on sleeping in a tent for one quarter to one half of the year. During the rest of the year he is largely occupied in preparing for the sledging journeys. He may have a dog team of his own, harnesses and traces to make, sledges to build and strengthen, tents and personal kit to re-condition. One is thrown on to one's own resources and ingenuity in polar regions to an extent not encountered in the civilised world. If, for example, you find that some protection against drift snow is required for your sleeping bag, then you must settle down to make one before your next sledging journey; the same applies to inadequacies in clothing and equipment. On a sledging journey attention to the smallest detail, and there are many, is essential, or one pays dearly for the oversight.

Forgetting to dry out a sock or glove in the tent overnight may mean agonies of discomfort to the owner, and also delay to the party next day.

The sledging equipment and methods used by F.I.D.S. have been developed by British explorers and are probably the best in the world. The two-man tents are pyramidal so as to stand high winds, the effect of a wind on one side being to force the two tent poles on the down-wind side even further into the snow. The tents are double-walled for additional insulation, the outer wall having a skirt projecting out from it on to which snow and ration boxes are piled, and the inner wall having a similar projection inside on which one lies, as an additional anchor for the tent (Plate 8). The tent material is made of an excellent completely windproof material. After a five-day gale I have emerged from the sleeve entrance of one of these tents to find that the snow level all round had been blown away to a depth of nine inches, leaving the tent secure on a nine inches high platform. In spite of this, it had weathered a gale strong enough to prevent us walking upright when feeding the dogs. It is surprising how warm the peak of the tent gets with a primus roaring in the tent, and one's clothes soon thaw and dry. A waterproof ground sheet, and good sleeping bag and skins to lie on, ensure a surprising measure of comfort when, all around, driving snow and intense cold might make life insupportable.

Our rations were austere, but very adequate. A plate of porridge and butter with a mug of cocoa for breakfast; during the halt for lunch, hot orange juice from a thermos, a 2 oz. bar of chocolate and a biscuit; and for the evening meal a gravy of pemmican, butter and peaflour, with a biscuit and a mug or two of tea. Although one started the evening meal with a ravenous appetite, by the end of the meal one felt very filled and satisfied, and a distant memory of roast duck and green peas would evoke little reaction compared to the same thought an hour earlier. The fact that few members of the Survey lost more than several

pounds on any journey is proof of the excellent composition of the sledging ration.

But before we men could settle down to appease our own appetites, our faithful dogs had to be fed. They might be lying quietly at the end of a day's run while we set up camp, but as soon as one man opened a box of dog pemmican the polar silence would be rent by the huskies' discordant howling, as they jumped at their tethering traces and slavered at the sight of the hard-earned pemmican. We had to be quick over the distribution of the dog food or an energetic pair of huskies might pull their tethering stakes out of the snow and cause chaos as they fought for other dogs' pemmican or made straight for the food box.

Navigation on a sledging journey is mainly by dead reckoning, with astronomical fixes obtained with a theodolite every sixty odd miles. Compass traverses are set (the leading sledge has a binnacle-type compass fitted to the handlebars) and the distance covered is measured by the rotations of a bicycle wheel registering on a milometer.

When mapping new territory the surveyor would call a halt hourly and take a prismatic compass bearing on to all salient features that were being mapped. This the surveyor correlated to sketch maps, plane table plottings and photographic panoramas made at the same time. Accurate rounds of angles were taken with the theodolite when the weather permitted, but on long journeys where the rations would only just last the trip, time spent at survey stations had to be curtailed. Difficulties in survey arising from bad weather and rations running short cannot be appreciated in England, and the remarkably fine maps of Graham Land which are now being published are a tribute to the perseverance of our surveyors, working with brain and fingers numbed by the cold.

Sledging journeys varied in duration from one week, for a short depot laying trip, to fourteen weeks on our longest journey of about 1,200 miles. The daily mileage on a journey is limited by the number of hours that the dogs can

keep up without getting unduly tired, and that is usually eight hours. On a long trip when conditions are ideal, twenty-eight miles is probably the maximum daily mileage to which the dogs should be pushed, though our record, established on the last twenty-four hours of a journey, is fifty-six miles. Too often, however, when the sledges bog in deep snow and stop in rough or steep terrain, a gruelling day's work will yield but a few miles of progress. At the end of such a day of perpetual lifting and tugging at a sledge loaded with over half a ton of stores, one feels almost too tired to cook and eat the evening brew of pemmican.

Much of our sledging travel and difficulties involved the negotiating of heavily crevassed glaciers. Until one has peered into the blue-green depths of a crevasse and let imagination run riot, one does not appreciate the danger that lurks under foot when crossing well bridged crevasses on a glacier. I have been lowered over one hundred feet into a crevasse to extricate a colleague who had fallen in and become wedged almost beyond aid, and can testify to the danger of such a fall. It is miraculous that this man was relatively unscathed.

Route finding in crevassed country from the ground is difficult, and in this respect aerial reconnaissance proved invaluable. Even travelling on the best routes, most of us put a foot through crevasse snow bridges or have actually gone through up to the waist more times than we can remember. Usually the incident is of no danger, as one holds on to the moving sledge or is roped to another member of the party; nevertheless, the danger is always lurking.

One day we were setting up camp on the shelf-ice on an apparently crevasse-free area. The surveyor stuck a ski upright into the snow to find to his horror that he had pierced the roof of a concealed crevasse that ran within a few inches of our tent. Normally, we travelled on ski to give us greater security against crevasses, as well as making travel very much easier, but on steep slopes and when travelling over wind-swept surfaces that had been whipped

up into iron-hard waves, or sastrugi, up to eighteen inches high, we had to discard the skis.

Most of us had sufficient narrow escapes to convince us that the country over which we travelled was amongst the most dangerous in the world.* One day, for instance, three of us were reconnoitring for a possible route down from the 5,000 ft. high plateau on to the shelf-ice. We had left our sledging camp with the fourth member of the party in charge of the two dog teams, while we took one team and a sledge to a cliff-edge overlooking the proposed glacier route down. We had started off on a perfect day, but the cliff-edge was deceptively far away. We travelled seven miles from our tents, and then left the dogs and sledge in order to proceed, roped together and on foot, a further three miles over steep crevassed slopes. We found our route down, but it nearly cost us our lives, as when ten miles from our tents we saw the ominous signs of snow drifting on the plateau. Running back to the sledge and dogs, we found them only just in time, as the drifting snow had almost obscured them. Starting back to the tents as fast as possible, we soon lost all traces of our outgoing tracks in the blinding drift. We were six miles from our tents, travelling over a flat, featureless snow plain into a wall of blinding drift with the aid of hand compasses and a sledge wheel milometer. From the back of the sledge at times I could not see the front of the sledge, let alone the dogs and my two companions, who were leading the lead dog. On these occasions, drift snow settles on one's face and eyelashes till all is a mask of ice. One has to keep clearing the ice from the eyelashes in order to see, and it was difficult to find the way into one's mouth for a small square of chocolate. When we had run out our seven miles by the sledge wheel reading, we turned at right angles and after a further half mile chanced upon a piece of lavatory paper. Never have I, nor ever will I, be so pleased to see a piece of soiled

*Since my return to England three members of the Survey have lost their lives.

toilet paper! After some searching, the dark shadows of the tents loomed up a few yards away. For the next few days visibility was nil, and with low temperatures and no food or means of digging a shelter, we could not possibly have survived had we not found the tents. As it was, we were already slightly frostbitten. After that episode we made a rule never to go further than three miles away from our tent when reconnoitring on foot.

On another occasion when two of us supported a small geological party on a coastal journey over sea-ice, we passed round a rocky headland that projected into the sea-ice. Returning ten days later, we were alarmed to find that the sea-ice along that strip of coast ten miles long had broken up and had been carried out into the South Pacific, and we subsequently learned that the break-up had occurred only a day or two after we had travelled over that stretch on the outward journey.

Flying, also, is none too safe. Our pilot recorded a sudden drop of two thousand feet in several seconds when flying over the coastal mountains. On one occasion, our plane was returning from a reconnaissance journey of the east coast, when it was caught in a sudden blizzard while crossing over the plateau. By dint of superb flying skill among the 8,000-ft. mountains in the storm, our pilot brought the aircraft on to the west coast, and in making a forced landing in the poor visibility, hit a small iceberg on the sea-ice and overturned. The three men in the aircraft were relatively unhurt. For days the storm raged, and when visibility cleared, the three found that they were trudging along, still sixty miles from base. At each step they were let into the snow up to the knees, and their feet wallowed in salt-water slush. They had a small one-man tent, seven pounds of pemmican and a small petrol-burning primus. They killed a seal with an ice-axe, and ate the liver. They were found on the tenth day twenty miles from base, each having lost twenty pounds in weight.

Since returning to civilisation I have often been asked

just how we were able to stand the cold. The cold was probably most noticed in the fingers, as a certain amount of outdoor work with the bare hands was essential. The agony of handling metal or ropes with bare fingers in a freezing wind is not easily forgotten. However most of us expected to notice the cold much more than we did. I have no doubt in my mind that one gets acclimatised to low environmental temperatures. On one or two occasions during the winter the temperature rose over fifty degrees Fahrenheit overnight and though the temperature was even then some degrees below freezing most of the men complained of the heat. While in the Antarctic I made some physiological investigations of this problem of cold acclimatisation, but, owing to difficulties hard to anticipate in the comfort of England, the results fell short of the programme planned.

In this short impression of our life, I hope that I have made the reader appreciate that if we got bored it was never from lack of something to do. The monotony of the colour tones of the landscape was appreciated at its fullest only when we feasted our eyes again on green grass on our return to Port Stanley in the Falkland Islands. I do not think that women in general, as delectable creatures to have around, were missed unduly, though those near and dear to one, and these mainly comprised wives and sweethearts, were badly missed. In our hut our social backgrounds were very mixed, but that did not matter. On the whole, our personalities blended happily, though at times, through the close daily contact, we got on each other's nerves. At all times, one could not help thinking what a good crowd of men they were, even if someone was keeping you awake by telling someone else an idiotic joke, for like as not that very morning he had, out of the goodness of his heart, brought you a cup of tea in bed.

Plates 7 to 14 are printed by courtesy of the Falkland Islands Dependencies Survey.

Veterinary Front

G. P. WEST

PROBABLY fewer people are familiar with the scope of veterinary science than with that of biology or medicine or physics. Obviously, it is directly concerned with the health of domestic animals; but indirectly it affects every housewife, every taxpayer and every child in the country. It has repercussions both upon human health and upon the economic life of the nation; upon our chances of contracting, say, anthrax or tuberculosis, and upon the maintenance and increase of our weekly rations. It has brought about the complete eradication from Britain of two diseases fatal in man: glanders – a loathsome disease involving the lymphatic system of the body – and rabies; and it has banished illnesses which, if reintroduced, might decimate our beef and dairy herds.

Bacteriology and Black Disease

One of the tasks of modern science is to determine under what conditions certain bacteria, frequently present. apparently harmlessly, in the bodies of healthy animals, are enabled or stimulated to become disease-producing. We know that in many cases insufficient food of the right kind, or sudden chilling, may lead to an animal becoming 'run down,' with a decline in its natural powers of resistance against such bacteria. But this generalisation is very vague and accounts for only a small proportion of cases of illness. Indeed, we sometimes find a contrary state of affairs: bacteria will attack the well-fed, thriving animal, while the one in poor condition escapes.

Such is the case with *Clostridium welchii*, Type D. This is an organism which – like the germ responsible for tetanus

or lock-jaw – is almost equally at home living in the soil or in the animal body. It can often be isolated from the digestive system of healthy lambs, but if conditions become favourable to its growth and toxin (poison) production, this organism will bring about the death of a lamb with great rapidity. What are these conditions? We do not know exactly, but we find that the germ almost invariably attacks well-fed lambs that are bigger and healthier-looking than their neighbours.

In order to obtain proof that this was really the case, some experiments were carried out in which one set of lambs were fed with cultures of the organism together with moderate quantities of milk, and the second set were given the culture together with large quantities of milk. It was found that the second set of lambs, which had enjoyed the greater quantity of milk, all succumbed to toxaemia (poisoning by the bacteria); while the others remained fit and well. Clearly, there is some relationship here between diet and the conditions in the digestive tract which favours the growth and toxin production of the bacteria, but precisely what that is we still do not know.

In Black Disease of sheep, on the other hand, we do know what stimulates the responsible organism to multiply; and here we have an interesting example of the association of parasites with bacteria in the production of disease.

Black Disease has been known for many years in Australia, and two recent investigations have established that it also occurs in one particular locality in the north of Scotland, and in one or two parts of the north of England. It affects only adult sheep in *good* condition (once again we notice this strange fact), aged between three and five years, and is observed during only four months of the year. It is prevalent during a mild autumn, but a sudden frost or a heavy snowfall appears to bring cases to an end.

Black Disease is dependent upon the association, first demonstrated in 1930, of a soil organism, *Clostridium oedematiens*, with a parasite known as the liver fluke,

Fasciola hepatica. Spores of the *Clostridium* become deposited on grass and other herbage, especially if too many sheep are grazed on the pasture or if the body of a dead sheep – perhaps hidden in undergrowth – has not been removed. These spores (bacteria inside a sort of protective coating) are eaten along with grass by the sheep, without ill effect, and some of them are carried from the digestive canal to the liver and spleen. Here, in their dormant state, the bacteria remain, and unless a fluke subsequently invades the liver, the sheep continues healthy and Black Disease will not result.

The adult liver fluke is a flattish, leaf-shaped parasite about 3 cm. in length (Plate 22). Its eggs are passed out of the sheep's body with the droppings and, after hatching, a minute larva must – if the life cycle is to continue – enter the body of a particular kind of snail called *Limnoea truncatula*. This is a small snail, with a long, thin, tapering shell, quite unlike the common garden snail, and it lives among the mud and weeds of ditches and swampy pasture.

Inside this snail the fluke larva lives and develops for a period of about six weeks, when it emerges in a different form – the second stage of development – and leaving the snail, climbs on to a blade of grass where it becomes encysted, a condition corresponding to that of the bacterial spores mentioned earlier. Next, if the life cycle of the fluke is to be completed, this encysted larva on the blade of grass must be eaten by a sheep. If this happens, the cyst gives rise to a young fluke which penetrates the bowel wall and migrates to the liver.

The tunnelling by the immature fluke, in the liver substance, itself causes severe destruction. Moreover, probably owing to toxic substances liberated by the fluke as well as to the purely mechanical damage inflicted by its protruding spines, neighbouring cells are killed. There follows an intense activity on the part of the sheep's white blood cells, which form a barrier around the dead tissue. Inside this in the zone of dead or damaged tissue, the spores of *Cl.*

oedematiens are stimulated into activity. The bacteria multiply rapidly, and produce toxins, or poisonous substances, which prove fatal to the sheep within a few hours (Plate 23).

Success has recently been obtained against this disease with the use of anti-*Clostridium oedematiens* serum. In one outbreak in which 26 out of 90 ewes in the flock had died, the serum prevented further deaths.

Biochemistry and Pasture

This is the age, in Man, of protective foods, and of a number of ailments due to the artificial conditions under which we live. In domestic animals we find the same thing: anaemia in pigs denied both access to grass and to a sufficiency of iron in the artificials fed to them; infertility in the bull kept in a dark loose-box and insufficiently exercised, and many other troubles of a like nature. But in animals which have free access to pasture we also find disease arising either because of some unnatural demand made upon them or because of some mineral shortage in the body. This opens up a big subject about which we know very little. What is the precise relationship between pasture management and disease in our farm animals?

We must not regard this as one simple problem to be wrapped up and conveniently disposed of under the label of 'mineral deficiency.' Sometimes the soil is indeed deficient in one or more minerals essential for animal health, but sometimes the herbage may lack in sufficient quantity what the soil contains. And often, on the other hand, the minerals are all there and are eaten in sufficient quantity by the grazing animal which, however, is unable to derive benefit from them because of some physiological disturbance, some impairment, of those chemical processes of the body which collectively we call metabolism.

Nor must we imagine that a given mineral deficiency can always be diagnosed by blood analysis. A condition known as *osteofibrosis*, for example, makes its appearance within twelve months in a horse fed exclusively on bran, a ration

very low in calcium and very high in phosphorus. Although the nature of the bones is materially altered, and they become very fragile, there is no noteworthy change in the blood content of either calcium or phosphorus. The diseased state could not be confirmed by blood analysis, although the deficiency of calcium in bran is known and the drain upon the calcium of the bones obvious. The reason for this is that the calcium dissolves out of the bones into the blood, and at the same time leaks out of the blood into the urine at the same rate, so that the blood level taken at any moment remains constant, just as the level of water in a bath would remain constant although there is no plug in the bottom, provided a tap is filling it up at a suitable rate.

As long ago as 1807 a shepherd noted that 'pine' – a disease of sheep characterised by progressive weakness, anaemia, and emaciation – occurred only in certain districts, and that it disappeared when the sheep were moved to other pastures which were often of low grazing value. At an early stage in the investigation of 'pine' in Scotland, it was believed that the trouble was due to iron deficiency, and indeed the administration of crude iron compounds produced an immediate curative response. Later, workers in Australia showed for the first time that cobalt plays an essential part in the nutrition of ruminants. They had been investigating a similar condition – 'coast disease' – which affects sheep confined in their grazing to the highly calcareous shell sand along the shores of southern Australia, and they observed a dramatic response to the administration of small doses of a soluble cobalt salt to badly affected animals. 'Bush sickness' of New Zealand had also been thought to be the result of iron deficiency, but the Australian workers proved that it was actually a cobalt deficiency and that the value of an iron treatment was due to the presence, as an impurity, of minute quantities of cobalt in the iron preparations employed. This fact was also quickly established in Scotland, where the disease occurs on soil derived from the porphorytic rocks of the Cheviots.

Certain moorland grazings of Devonshire, Northumberland and North Wales have also been shown to produce 'pine', which is a true deficiency disease (Plate 20).

An example of what is sometimes called a 'mineral imbalance', rather than a mineral deficiency, is to be found in *hypocalcaemia* – a condition met with in dairy cows, usually shortly after calving. Up till 1897 this disease, which was called 'milk fever' (although it is not a fever at all), proved fatal in a very high proportion of cases. In that year a Danish veterinary surgeon, thinking the trouble was due to an infection, obtained some success by the infusion of an antiseptic solution into the udder. It was soon found that better results followed simple inflation of the udder, and this procedure – using air, oxygen or carbon dioxide – was carried out for many years, and in the vast majority of cases brought about a rapid recovery. The cow which had been lying helpless on the ground was on its feet again within a couple of hours.

It was later shown that this milk fever was really an example of *hypocalcaemia* – a fall in the level of the blood calcium. This being so, it was reasoned that the administration of a solution of calcium salts into a vein or under the skin should bring about the curative effect which udder inflation gave. It was found that in almost all cases it did, so the new and more rational treatment was adopted.

It should be noted that *hypocalcaemia*, although it occurs less commonly on chalky soils, is not a deficiency disease in the accepted sense of that term. Liming of the pastures, or the addition of calcium salts to the feed, are not sufficient to prevent the onset of the malady. The level of the calcium in the blood falls, although the intake of calcium by the mouth remains constant.

That the severe demands of pregnancy and lactation upon the system should sometimes exert a serious drain on the blood calcium was not altogether surprising; what was more difficult to understand was how a purely mechanical process, such as distension of the udder, could restore the

calcium content of the blood to normal. For many years this remained an intriguing problem, and it is one which is not entirely solved yet.

A theory put forward in 1925 was that *hypocalcaemia* resulted from decreased activity on the part of the parathyroid glands. Two years later it was suggested that more than one of the endocrine glands were involved, and that there was in addition a disturbance of the sympathetic nervous system. It now seems that the whole 'nervous-endocrine system' is involved; that is to say, the hormone-secreting glands as a whole, together with the two nervous systems – sympathetic and parasympathetic.

It has been shown that a cow in full lactation not infrequently secretes daily in the milk about twelve times the total amount of calcium present in all her blood. Since the calcium salts of the milk come from the bloodstream, it follows that the blood calcium must be replaced completely at least twelve times a day. If the calcium metabolism is disturbed, and less calcium supplied to the bloodstream than is secreted in the milk, then symptoms of *hypocalcaemia* develop.

Recent experimental work suggests that the exaggerated development of the cow as a milk-producer brings about over-activity of the pituitary gland. The latter secretes hormones to an extent which probably upsets the endocrine balance, and the birth of a calf is a sufficient stimulus to cause the onset of *hypocalcaemia*. Administering calcium or inflating the udder stimulates the sympathetic nervous system, and so offsets the previously increased activity of the parasympathetic system. Such is the view of Dr Seekles, Professor of Veterinary Biochemistry at Utrecht, who suggests that the balance might also be restored by the administration of a hormone from the adrenal or parathyroid glands. It must be added, however, that the original picture of so-called Milk Fever has been broadened by an examination of blood samples extending back over the last fifteen years; and these samples have shown that the illness

is not associated merely with a shortage of calcium, but also with a shortage of phosphorus and either too much, or too little, magnesium. And it seems that while you cannot, in practice, *prevent* Milk Fever by giving a cow additional calcium in her diet, the seasonal decline in the level of magnesium in the grass may give rise to one type of Milk Fever.

Veterinary preventive medicine in the Dominions and Colonies

In the Dominions and Colonies veterinary preventive medicine often bristles with problems which do not confront us in Britain. Many of the sparsely inhabited territories are vast in size, with scrub or jungle covering wide areas and harbouring disease-carrying flies, and also wild animals which act as reservoirs of bacteria, viruses, and protozoan parasites. Climate, lack of transport facilities and a shortage of manpower all add to the difficulties. In consequence, the ordinary methods of disease-control have often to be practised on a heroic scale. During 1945, for example, as many as 2,245,913 inoculations against rinderpest were carried out in Tanganyika, where there is only one field veterinary officer to every 300,000 head of cattle.

Disease-control measures commonly take one of two forms. An attack may be directed against the fly or tick responsible for spreading the disease, or against the organism which actually produces the disease. Thus a vaccine is used to confer immunity against the virus which causes rinderpest – a cattle plague which ravaged Europe intermittently for fifteen centuries, but is now mostly confined to Asia and Africa. And the outstanding discovery of the drug phenanthridium 1535 means that we can attack, likewise in the animal's body, the parasite *Trypanosoma congolense*. On the other hand, as the following example will show, some diseases can be eradicated or brought under control by the mass use of insecticides against the flies or ticks which spread the infection.

The Brown Cattle Tick, which transmits the piroplasm (organism) responsible for a disease known as Texas Fever, was completely eradicated from the British Virgin Islands in the West Indies within the space of four years. Tanks were constructed and so placed that no cattle had to be driven more than five miles for dipping, which was made compulsory and carried out fortnightly. The only ticks now left in the Virgin Islands are the tropical horse-ticks, resistant to the dip on account of their waxy cuticle, and non-transmitters anyway; and compulsory dipping has consequently now been abandoned. By this energetic use of a simple means, Texas Fever has been banished from the islands.

In Africa, particularly equatorial Africa, the twenty-odd species of tsetse flies constitute by far the greatest problem with which that continent has to contend. In the presence of tsetse flies it is impossible for a large community of human beings to exist. In the first place, man may be directly affected by the fatal disease, sleeping sickness. Secondly, in areas where this danger is non-existent, a disease of cattle – Nagana – makes it virtually impossible to keep stock ; and man and his domestic animals are inseparable.

All tsetse flies have one requirement in common – an assured regular food supply in the form of the blood of animals – but beyond that each species has its own requirements, or preferences, with regard to the type of country it infests. *Glossina pallidipes*, the tsetse fly which transmits the trypanosome of Nagana (Plate 21), infests typical savannah bush veld, and can feed upon the smaller species of game such as the warthog, bushpig, bushbuck, etc., as well as the wild antelope, which is regarded as the staple blood-supplier to all tsetse flies. In dealing with this fly, neither the destruction of the larger game nor bush-clearance offer a practicable solution to the problem. Some direct method of attack upon the fly itself was therefore indicated.

The Harris Fly Trap had for many years provided a useful guide to the size of the tsetse population, but it had not

brought about a reduction in numbers. Accordingly, experiments were begun in 1945 to observe the effects of D.D.T. sprayed from aircraft. In the early experiments an oily emulsion containing D.D.T. was atomized in the aircraft's slipstream, and delivered at a rate which allowed one gallon of spray for each acre. In later experiments D.D.T., dissolved in toluene and fuel oil, was fed into the exhaust manifold of each of the plane's engines, with the consequent production of a dense white smoke. By this method, an aircraft flying at 120 m.p.h. could cover 50 acres per minute, the swathe width being about 70 yards.

The area chosen for the experiments was the Mkuzi Game Reserve, and surrounding bush, covering 40 square miles, and having a high density of fly together with an ample number of host animals. This area was covered in ten flying hours during August, 1946. The best time was found to be in the early mornings, when the smoke sank immediately into the bush and, for an hour or two, remained there as a mist. Flies were collected and exposed in special cages in various situations, including extremely dense thickets. In two exposure experiments under adverse weather conditions, 100 per cent mortality resulted in one case and 85 per cent in the other.

The smoke applications were continued over a period of four months in order to make certain of catching the unhatched tsetse pupae assumed to have been present at the beginning of operations, and so prevent the production of further tsetse larvae. At the end of that time – although total eradication had not yet been achieved – the tsetse fly incidence, as revealed by Harris Fly Traps together with careful observations, had been reduced to a level at which the natural mortality of this slow-breeding parasite might be expected to result in its total elimination. This would have meant an end of Nagana in the sprayed areas – an indirect victory over the trypanosome. The results of the last two years indicate, however, that the victory has not everywhere been complete – a small percentage of the tsetse

population managing to survive. It is this fact which has led to such hope being pinned on Antrycide, the new synthetic drug which is replacing earlier ones used against trypanosomes living in the bloodstream of cattle. It is too soon yet to say whether Antrycide will offer a practical means of *preventing* the disease, as opposed to treating it.

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For permission to use plates 20–23 of the inset, we are grateful to Dr. J. Stewart, Moredun Institute (plate 20).

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The Structure of Proteins

J. C. KENDREW

VERY often the most fascinating and productive advances in science take place at the borderline between two or more of its branches. One borderline which is just now in a state of most fruitful activity is that between biology, chemistry, and physics. It is many years since the first two of these entered into partnership to form the new science of biochemistry, whose object is to elucidate the chemical behaviour of living systems. A more recent development has been the extension of the methods of physics into the biological sphere, and in this way has come into existence a field of research which lies at the meeting point of the three original sciences. Among problems in this field there is none more important, more intractable, or more fascinating than that which forms the subject of the present article.

I. The nature, occurrence and chemical composition of proteins

Some common proteins. Let us first try to gain a clear idea of where proteins are found and what they are. This is not easy because proteins are very widespread, making up the greater and more important part of all living matter, and are extremely diverse in properties and functions. Perhaps the name is most often met with in dietetic contexts; we are all familiar with the generalization that foodstuffs mainly consist of varying proportions of fats, carbohydrates, and proteins – and this generalization is useful because it does summarize the principal components of all living matter. Of common foods, the one which contains the highest proportion of protein is lean meat. Indeed, meat is merely

the butcher's name for muscle, and its main protein is myosin, a member of the class known as fibrous proteins. The fibrous structure of meat can easily be seen under the microscope (even when it cannot be appreciated by more direct means), and its characteristic property of contractility, the mechanism of which is still little understood, is familiar in every living animal.

Another food substance which consists very largely of protein in relatively pure form, is egg white. This egg albumin, as it is called, is a typical member of the other main subdivision, the globular proteins (sometimes known as the corpuscular proteins). This name was applied at a time when there was little real knowledge of the shapes of protein molecules, and was suggested mainly by contrast with fibrous ones; however, the name has been shown by later research to be fully justified. Egg white displays all the characteristic properties of globular proteins. For example, in dilute form it gives a clear solution in water; when more concentrated, a gel or jelly of high viscosity. If high concentrations of neutral salts such as ammonium sulphate (normally used because it is relatively inert and does not affect the protein) are added to the albumin solution, the protein is precipitated, and this precipitate can be redissolved in water without the protein having undergone any alteration. It is also precipitated from solution on boiling, but this time some irreversible change has occurred, for the precipitate will not redissolve on cooling; this change is familiar in the boiled egg and is known as denaturation. As to the function of egg albumin in an egg, its rôle is to form a protein store for the growing embryo, which uses it to build up its own tissues until such time as it achieves free life and can search for its own food.

Another protein which is very familiar, though under other names, is keratin (from the Greek κέρας=horn). This substance is the main constituent of hair, wool, and horn, and as is natural in view of the obvious properties of these materials it is classified as a fibrous protein. Keratin is

insoluble in water and very inert chemically, and the remarkable diversity of chemical properties and physical behaviour which is exhibited by proteins is well illustrated by the contrast between it and our next example, the enzymes.

A striking characteristic of living organisms is that they are able to carry out swiftly and at body temperature numerous chemical reactions which the organic chemist either cannot imitate at all, or else is able to carry out only by the use of high temperatures and powerful reagents such as strong acids. For example a piece of dry bread begins to taste sweet after it has been chewed for a while; the saliva has broken down some of the starch in the bread to sugar, a reaction which is carried to completion during digestion. If the same reaction is carried out by ordinary chemical means it is necessary to boil the starch with dilute acid. Again, every green plant is able to use the radiant energy of the sun to convert atmospheric carbon dioxide into sugar, by means of a complicated series of processes, known as photosynthesis, about which we still understand very little and which we are quite unable to imitate in the test tube. The early biochemists were able to show that these remarkable reactions were made possible by the presence in living cells of minute traces of substances akin to the catalysts of chemical industry – substances capable of enormously increasing the rate at which some particular chemical reaction is carried out, without themselves being changed at the end of it. These substances were called enzymes (from the Greek ἐν ζύμῃ=in yeast) and they are relevant to our present argument for the reason that every known enzyme is a protein. Life as we know it would be quite impossible without the intervention of enzymes, and hence it can be stated with truth that proteins are the *sine qua non* of life.

There is an extreme contrast between the unparalleled chemical activity of enzymes, and the inertness of horn. Yet both are proteins – and this contrast in activity and in function illustrates not only the ubiquity and indispensability

of proteins in living cells, but also the difficulty of comprehending them under any simple, tidy definition. The word protein is derived from the Greek πρῶτος, meaning *first*; but a derivation from Proteus, the old sea-god who was able to assume many different shapes in order to avoid revealing his secrets, though incorrect, might seem equally appropriate. In fact the reader may be wondering what justification there is for including under the single name 'protein' substances so various in behaviour and in function. The reason lies in their common basis of chemical composition, a matter which we shall discuss in the next section but one.

Early studies of proteins. The many-sided nature of proteins was one feature which made their study very difficult in the early days of biochemistry. Another was their habit of forming gels and other types of colloidal aggregate of the kind which the classical chemist regarded merely as a mess and a nuisance and poured without regrets down the sink. These unsatisfactory properties are displayed by proteins in a pure state; *a fortiori* the complex mixture of proteins and other materials found in the living cell, and collectively referred to as protoplasm, proved quite beyond the powers of earlier chemical techniques to deal with at all.

So progress was very slow in those days, and it was only when, as technique improved, it became possible in a few cases to isolate components of protoplasmic mixtures with more or less definite and reproducible properties, that the bold and hitherto unjustified assumption was made that proteins might be regarded as definite and distinct chemical entities, in spite of their frequent appearance as slimes or gels. The assumption that proteins possessed chemical individualities was a prerequisite for further progress, and only after this fundamental development in outlook had taken place did it become reasonable to pursue attempts to isolate pure proteins, to describe and compare their properties, and to begin to think of a chemical structure in the ordinary sense. Progress was hastened by the discovery that

proteins do not, after all, invariably behave in their usual unsatisfactory manner, but that sometimes they can be persuaded to crystallize like any well-behaved inorganic material. The first acknowledged protein to be crystallized was egg albumin, and it has been followed by many others.

But increasing mastery of techniques for dealing with proteins in the laboratory did not immediately lead to a discovery of what their chemical structure, so hesitatingly postulated in the first instance, actually was; it served rather to show that in the proteins is to be found a complexity unparalleled among any of the other classes of chemical compounds studied by the chemist. Indeed after years of intensive application of every relevant physical and chemical method we still have no more than scanty knowledge of the structure of the most simple proteins. And even setting aside the goal of complete structure determination, the little we now know about their constitution has not done much to help us to explain their biological properties. The examples already quoted are sufficient to illustrate the variety of behaviour which they exhibit; in few cases are we able to correlate these variations with any corresponding features of structure or chemical composition – and in the few cases where a correlation does exist, it is partial and limited in scope.

The purpose of this article is to give an account of such knowledge as we do possess about protein structure and to indicate the magnitude of the problems which lie ahead. The reasons why it is so important to solve these problems, and why their solution must lead to far-reaching advances in our understanding of the working of living organisms, will be easier to appreciate after we have discussed the present state of knowledge of the chemical composition of proteins.

The chemical nature of proteins. For many years some basic facts have been well established. In the second half of the nineteenth century organic chemists made many investigations of natural products to see what chemical elements

they contained; those which we now know as proteins were found to contain not only carbon, hydrogen, and oxygen like all other organic compounds, but also invariably nitrogen and often small amounts of sulphur, as well as many other elements in particular cases. In this respect they differed from the two other main classes of substance found in living matter, the carbohydrates and the fats, which generally contain only carbon, hydrogen, and oxygen.

By about the end of the last century it was becoming clear that all proteins could readily be broken down to complex mixtures of small molecules whose structures were individually well known to chemists. This breakdown occurs when proteins are boiled with dilute acids or alkalis, and analysis of the contents of the stomach and small intestine shows that exactly the same process takes place during digestion. It consists in breaking the molecule into two or more pieces with the addition of the elements of water, a type of reaction very common in organic chemistry and known as hydrolysis; in the general case it may be written

$$X—Y + H_2O \rightleftharpoons X—H + HO—Y$$

The vast majority of the simple compounds which can be isolated from the mixture obtained by hydrolysing a protein completely belong to the class of α-amino acids. These are compounds containing both a —COOH or carboxyl group, and an $—NH_2$ or amino group, attached to the same carbon atom, known as the α-carbon atom; their formula may be written

$$\begin{array}{c} R \\ | \\ NH_2—CH—COOH \end{array}$$

where R— is a different chemical grouping in each amino acid. In organic compounds the carboxyl group is characteristic of acids, while the amino group confers basic or

alkaline properties: thus amino acids partake of the characteristics of both acids and bases.

The possibility of hydrolysing proteins to mixtures consisting almost entirely of α-amino acids was recognized to be one of their fundamental properties, and indeed a protein soon came to be *defined* as a complex molecule which, on hydrolysis, yields such a mixture. This is the common chemical property underlying the diversity exhibited by enzymes, by hair and horn, by muscle, and by all the other constituents of living matter known as proteins.

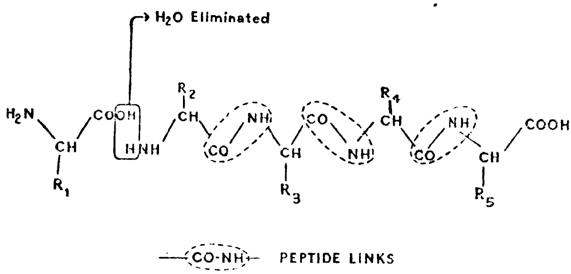


Fig. 8. – Polypeptide chain.

The next step was the suggestion, put forward almost simultaneously by Fischer and by Hofmeister in 1902, that in proteins the amino-acids are linked together in long *polypeptide chains* by means of *peptide links*, formed by the elimination of the elements of water from amino- and carboxyl- groups of adjacent amino-acids; the scheme is illustrated diagrammatically in Fig. 8. The hydrolysis of proteins evidently consists in the addition of the elements of water at the peptide links, reconstituting the complete amino-acid molecules. In the complete hydrolysis of a protein many such links must be broken successively, the molecule being split up into smaller and smaller fragments as hydrolysis proceeds.

Fischer and Abderhalden were able to synthesize polypeptides containing eighteen or nineteen amino-acid groups,

and although synthetic molecules of this type were clearly much smaller and simpler than a protein proper, it was found that the longer the polypeptide chain the more did the synthetic compound begin to resemble proteins in some of its properties. Recently synthetic polypeptides have been prepared which contain a very large number indeed of amino-acids, and these resemble proteins still more closely. The work done in the years which followed the syntheses of Fischer and Abderhalden has strengthened the polypeptide chain hypothesis, and at the present time there is no real evidence of the presence in proteins of any form of main structural link other than the peptide bond, —CO—NH—, between neighbouring amino-acids.

The α-amino acids have been represented above by the general formula R—CH(NH_2)—COOH. The group R— is known for obvious reasons as the *side chain* (see Fig. 8), and it may be a simple hydrocarbon (alkyl) group or a more complicated substituted one; in all between 20 and 25 different amino-acids, bearing different R— groups, have been found in the hydrolysates of proteins. A representative selection is shown in Fig. 9.

The odd thing about the list of naturally occurring amino-acids is its shortness. It is true that the natural amino-acids are all relatively simple in structure, but a chemist could write down the formulae of, and synthesize in the laboratory, hundreds equally simple. It is very strange that Nature, usually so much more versatile than any chemist, should have restricted herself to a list of twenty or so. Generally any given protein will not be found to contain them all, but those it does contain are always members of this same list, whether the protein be derived from the most lowly micro-organism or from a highly-developed mammal. Whether this simplicity represents the end-stage of a lengthy process of evolutionary natural selection; or whether the choice is limited by the operation of overriding physico-chemical factors at whose nature we can only guess, remains a major riddle of protein chemistry.

Some typical amino-acids, R—CH(NH$_2$). COOH

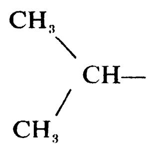
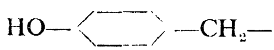
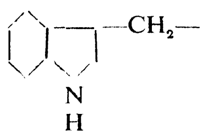
R	=	H—	glycine
	=	CH_3—	alanine
	=		valine
	=	HOOC . CH_2 . CH_2—	glutamic acid
	=		tyrosine
	=		tryptophan
	=	HS . CH_2—	cysteine
	=	H_2N . CH_2 . CH_2 . CH_2 . CH_2 —	lysine

Figure 9.

II. The molecular weights and detailed amino-acid compositions of proteins

Molecular weight. We mentioned above that synthetic polypeptides were simpler and smaller than proteins. It was early realized that it is important to discover just how large protein molecules actually are, in other words to measure their molecular weights. It was known that proteins in

solution behaved like colloids, and presumably shared with them the property of having very large molecules. But although the measurement of the osmotic pressure of haemoglobin solutions as early as 1904 had indicated a molecular weight of 50,000 for this protein – not so very far removed from the now accepted value of 66,700 – the theory of the method was not fully understood, nor were methods of purification advanced enough to ensure that the protein examined was homogeneous. So it is only in the last 25 years that reasonably accurate figures have been available.

Many methods have been used. One of the most important is the measurement of osmotic pressure, mentioned above; osmotic pressure is one of a series of properties of solutions (others are change in freezing point and boiling point, and change in vapour pressure) which are simple functions of the number of molecules present in unit volume of the solution, just as the pressure of a gas is a function of the number of gas molecules present in unit volume. Given the total weight of protein and the number of molecules per unit volume, it is possible at once to obtain the molecular weight. The technique is difficult, but in the hands of many workers, headed by Sörensen and Adair, it has been developed to the stage where it can give values as accurate as any available.

Another very valuable method is sedimentation in the ultracentrifuge, which was developed by Svedberg and his collaborators at Upsala. It consists essentially in whirling round a solution of the material under test so rapidly that it is subjected to a centrifugal force many thousand times the force of gravity. Under the influence of this force large dissolved molecules such as proteins are forced outwards towards the far end of the tube containing the solution. The heavier the dissolved molecule the faster it is forced outwards; by measuring the rate at which this centrifugal sedimentation takes place, or by observing the final distribution of dissolved material in the cell when equilibrium has been reached after a long run, it is possible, with the aid

of a number of supplementary measurements, to calculate the molecular weight of the protein.

Two important generalizations may be made about the results of such measurements. The first is that the molecular weight of all proteins is very great, the smallest being about 12,000 and the largest several millions – expressed on the usual scale in which the weight of the hydrogen atom is given a value nearly equal to one. The second is that, at any rate if we confine ourselves to the globular proteins, the molecular weight is an invariable quantity characteristic of each protein (except in a few cases in which it has been demonstrated that splitting into smaller sub-molecules may take place in special circumstances). This is additional evidence that every protein possesses a definite individuality; in other words, that it is reasonable to speak of the molecule of a protein just as we speak of the molecule of ethyl alcohol or of glucose.

Amino-acid composition. The accurate characterization of the amino-acids contained in proteins is a very difficult problem. The different amino-acids have rather similar (in some cases extremely similar) properties, and up to twenty different ones may occur in the mixture obtained on hydrolysing a single protein. Separation of the amino-acids in the mixture, and determination of the amounts of each present, are extremely tedious and difficult processes to carry out accurately. Only during the last few years have adequate techniques been worked out, and even now it is doubtful whether a completely accurate analysis of any protein has been achieved. An example of a protein which has been subjected to an intensive analysis is insulin, about which Chibnall has stated that, out of a total of 106 amino-acids contained in each basic unit (of molecular weight 12,000) the identities of 101 or perhaps 102 are known with fair certainty. Only in a few cases do we possess nearly as much information as this. Much speculation has been devoted to attempts to deduce significant relations between the numbers of different amino-acids present in various proteins;

it cannot be said that they have been very successful, nor is this surprising in view of our continuing uncertainty about the amino-acid composition of nearly all proteins.

III. The architecture of the protein molecule

Assuming that we possessed a complete list of the amino-acids in a particular protein, together with the numbers of molecules of each present, we should be faced with three further questions:

First, in what order are the amino-acids arranged along the polypeptide chains?

Second, does a single protein molecule contain only one continuous polypeptide chain, or several – and if the latter, how many?

Third, how are the polypeptide chains arranged in space to make up the complete molecule?

None of these questions can yet be answered completely, but we may consider what may be said about each in turn.

The order of amino-acids along the chain. Since nearly all proteins contain most of the twenty odd amino-acids, the number of possible permutations of these in a linear arrangement is very large. And our knowledge of the actual order in any one protein is extraordinarily meagre. So far almost the only technique which gives any useful information is the hydrolysis of the protein under carefully controlled conditions, arresting the process just before it is complete. At this stage not all the peptide links have been hydrolysed, and the reaction mixture contains pairs and triplets of amino-acids, still connected together in their original order. Separation and identification of these di- and tri-peptides, as they are called, leads to a knowledge of some 'nearest neighbours' in the intact protein molecule. Unfortunately peptides are even more difficult to differentiate and identify than are single amino-acids, so the method has not been widely applied nor has it yielded more than fragmentary information. Indeed it may never

do so; it must be presumed that some peptide links are more unstable and more easily broken than others, and are therefore hydrolysed at an early stage, so that the amino-acids adjoining them would never appear coupled together as a dipeptide in the partial hydrolysate.

A related method, of equally limited application, makes use of enzymes. The digestive systems of animals contain enzymes whose function is to break down the proteins of the food into their constituent amino-acids, which are then absorbed into the body; there exist several of these proteolytic enzymes and each is found to attack a specific type of peptide link.* By using purified enzymes of this kind *in vitro*, it is possible to deduce the presence or absence of these specific types of link in the protein under examination. Various complications, in particular the occurrence of reverse reactions resynthesizing peptide links (perhaps different from the initial ones), make the results obtained very difficult to interpret with certainty.

The number of polypeptide chains. Our second question is whether protein molecules contain one single chain, or whether they have a more complex structure, several chains being attached together not by peptide bonds but by some form of secondary linkage. This problem has been investigated by Sanger and his collaborators, who have developed what is known as the 'end-group' method. Reference to Fig. 8 shows that a single polypeptide chain contains only one free, unattached α-amino group – at the extreme left-hand end as drawn in the Figure (it is necessary to specify α-amino groups, i.e. those attached to the same carbon atom as the carboxyl group, because certain amino-acids contain a second $—NH_2$ group in their side-chain; one example – lysine – is shown in Fig. 9). If therefore we can count the number of free α-amino groups in the intact protein molecule, we at once know the number of independent polypeptide chains in that molecule, since each chain is repre-

* i.e., peptide links differ according to which two amino-acids they join.

sented by one free α-amino group. Sanger's method is to mark the free α-amino groups in the molecule by allowing the protein to react with a reagent which attaches itself to free $—NH_2$ groups, and to no others; the protein is then fully hydrolysed in the usual way. During hydrolysis the marking compound remains attached to the amino groups, so the hydrolysate contains, for every free α-amino group in the original molecule, one marked amino-acid. The number of these per molecule must be equal to the number of free α-amino groups in the protein, and therefore to the number of independent polypeptide chains; the identity of the marked acids shows which amino-acids occupied terminal positions. Two difficulties hamper the method. The first, which can easily be overcome, is that the marking compound also attaches itself to side-chain amino groups such as that of lysine; however these side-chain marked amino-acids can be separated relatively easily from the hydrolysate. The second difficulty is more serious, namely that there is no obvious reason why the free —COOH at one end of a polypeptide chain should not link up with the free $—NH_2$ at the other to form a cyclical arrangement, whose existence would not be suspected in the end-group method since there would no longer be any free α-amino groups. So far no evidence is to hand either for or against the presence of cyclical arrangements in proteins, though they are known to occur in simpler molecules. For example, the naturally-occurring bactericide gramicidin-S, which was recently isolated from the micro-organism *B. brevis*, has been shown by application of the end-group method to contain no free α-amino groups, and it is believed to be a cyclical system of either five or ten amino-acid residues – a polypeptide chain chasing its own tail.

Leaving aside the possibility that such cyclical polypeptide chains may occur in proteins, Sanger's method tells us how many separate chains any given protein contains – for example, in horse haemoglobin six 'end-groups' are found, and so there are six chains, each of which terminates

with a valine molecule. Presumably these chains are connected into a single molecule by some form of linkage other than the peptide bond, but so far we know little about these inter-chain linkages.

The arrangement of polypeptide chains in space: the stereochemistry of proteins. We have now mentioned some of the methods available for answering the first two of the questions posed above. At least, in principle they are capable of answering them: in practice they are tedious and difficult to apply, and in any case they are of fairly recent invention, so that up to now they have not been used very widely. Nevertheless there is no doubt that, with the passage of time, these methods and others like them will enable us to build up a comprehensive picture of the number of polypeptide chains and of the arrangement of amino-acids in protein molecules.

We now turn to the third of our questions, namely, how the polypeptide chains are arranged in space to make up the complete molecule. This is the biggest question of all, and the one to which the least adequate answers have been given. Classical organic chemists showed many years ago that, even in simple compounds, the spatial arrangement of the constituent atoms has a decisive influence on the properties of the molecule, and that two molecules containing the same atoms bound to the same neighbours, but spread out three-dimensionally in different ways, may display great differences as a result of their different arrangements in space: such compounds are called stereoisomers. The possibilities of stereoisomerism increase enormously with the number of atoms in the molecule, and when we reach the complexity of proteins with molecular weights ranging up to millions, the number of possible stereoisomers becomes astronomical. Take a simple case where the protein molecule contains only one polypeptide chain. Its configuration is governed by certain rules about the lengths of the bonds between the individual atoms composing it, and about the angles between these bonds. Even when these conditions

have been satisfied the chain remains quite flexible and the number of ways of arranging it in space is nearly as great as the number of ways of arranging the sort of chain we meet in everyday life, made of metal links. It might be straight: it might be coiled: it might be arranged in zigzags. The possible variations on these themes and combinations between them are almost beyond number. So far all our researches have done little more than narrow down the possibilities. Indeed in our present ignorance of the spatial arrangement of the chains, and of the order of the amino-acids within them, we are in the situation of an archæologist trying to deduce the structure of an ancient building, given only a rubbish heap containing the stones of which it had been built, mostly separate, but a few still attached together by mortar giving him a vague inkling of the possible ways they had been laid in the complete structure.

This is the jig-saw puzzle which we have to solve. It seems fairly clear that purely chemical reasoning is insufficient for the task; for although organic chemists, using classical chemical technique, have built up a most impressive body of knowledge about the spatial arrangements of atoms in molecules – which has been confirmed in all essentials by X-ray crystallography and other physical methods – this knowledge refers to molecules immeasurably simpler than the proteins. More direct methods of investigation are needed to supplement the chemical ones, and this is where the newer physical techniques are beginning to make an appreciable contribution to the problem. The later part of this article will be largely devoted to a brief outline of some of the results achieved by application of these new methods.

We end our remarks about the complexities of molecules so large as those of the proteins, by pointing out that attempts to unravel them are stimulated and justified only by the faith that each protein does indeed possess a definite and invariable structure. We noted at the beginning of this article that in early days real progress in investigating these

unstable, 'messy', compounds became possible only when the theoretical step had been taken of crediting them with definite chemical individualities. Since that time we have come to realise more clearly how large is the number of possible configurations of protein molecules, so large indeed that faith in a specific, reproducible, constitution for each protein might well have been shaken. Fortunately this realization has been accompanied by ever more accurate measurements of the properties of proteins, and by more adequate means of purifying and separating them. As a result our faith has rather been strengthened; pure preparations of a protein have identical properties, whenever and by whomsoever they are made. More accurate methods of amino-acid analysis lead to more accurately reproducible results; different methods of determining the molecular weight of the same protein yield more concordant results as those methods are improved.

That some protein preparations still obstinately fall short of the ideal of reproductible properties, indeed that in some cases the so-called individual protein in its natural surroundings may be a variable entity, cannot be denied; but that most do possess a definite, specific structure, down to the individual atoms of which they are composed, seems now quite certain. The nature of this structure – the exact way in which the chains are folded and the identity of the amino-acids of which they are composed – determines the shape of the molecule, and the pattern of side-chains protruding from its surface; and these in turn must be responsible for all the variations in function and properties which proteins display.

Once the structure of the molecule has been determined, the way is open to correlate it with the properties, chemical and physiological, of the protein. We may then be able to answer a multitude of questions. Why can haemoglobin act as an oxygen carrier? Why is keratin fibrous? Why can a particular enzyme system break down glucose to carbon dioxide and water while it leaves other closely related sugars com-

pletely untouched? The hope of answering these questions, and innumerable others of the same sort, is the justification of research into the nature of the protein molecule. To say that an understanding of the structure of proteins will be the key to life is picturesque but perhaps misleading; such understanding will, however, undoubtedly give us deeper insight into the nature of the chemical processes which are the manifestation of life.

IV. The two main types of protein

It will be useful to say a little more about the division of proteins into two broad classes. This division was arrived at more or less intuitively in the early days of protein research, but the physical techniques we are about to describe have confirmed intuition.

Broadly, proteins are classified into the fibrous and the globular. The fibrous ones comprise in the main the structural materials of animals (the structural components of plants are generally polysaccharides and not proteins) such as the keratin of hair, wool, epidermis and feather, the collagen of tendons, myosin of muscle, and silk. With some exceptions (including myosin) their function seems to be mainly architectural; we have already noted that they are rather inert chemically, and in living animals they generally take no active part in metabolic processes. Their name was acquired naturally from observations of their macroscopic and microscopic appearance and there seems no doubt that this structure is paralleled on the submicroscopic scale.

The globular proteins, on the other hand, are chemically active and soluble; they comprise the major portion of the solid constituents of protoplasm and of the solutions which form the body fluids, and in particular the enzymes, those most active of all proteins, are almost all members of the globular class. Of recent years, solutions have been studied by a number of methods which throw some light on the shape of dissolved molecules and can, for example, dis-

tinguish between a more or less spherical particle and the long thread-like molecules of a linear polymer (such as rubber and many of the new synthetic plastics, which are formed by repeated condensation, end to end, of large numbers of small molecules). The application of these methods has justified the term globular protein, for it seems that these substances do in fact consist of molecules not far removed from the spherical. Or perhaps it would be more correct to say that in molecules of a globular protein the three dimensions are of comparable magnitude and that each of the three is characteristic of that molecule. On the other hand, in a fibrous protein one dimension is much longer than the other two, and can presumably assume any value within limits – just as, within limits, a piece of string may be of any length and still remain a piece of string.

One of the most fundamental problems has been the relation between fibrous and globular proteins. The problem was posed as follows in 1936 by Astbury, whose investigations of fibrous proteins by means of X-rays have contributed much of our knowledge of protein structure up to now.

> 'Which is the more fundamental, the globular form or the chain form, and is one obtained from the other by a process of simple coiling or uncoiling, or is the chain form a consequence of the linear polymerization or condensation of the globular form?'

– in other words, are we to suppose that the fundamental unit structure of a fibrous protein is a simple polypeptide chain, and that a globular protein is formed by the coiling or folding of such chains; or, given this type of structure for the globular protein, is the fibrous protein derived by linear aggregation of similar globular particles, like a string of beads or a pound of sausages?

Until very recently all the evidence seemed to point to the former as the correct solution; but new results make it seem just possible that after all the latter may have something to be said for it. So far there is no conclusive evidence

and the whole problem is in a most exciting state of indecision. We shall return to it after a brief account of earlier researches.

V. Fibrous proteins, globular proteins, and viruses

The fibrous proteins. We have remarked that Astbury and his school have carried out researches of fundamental importance in the field of fibrous proteins, using the methods of X-ray crystallography. Space does not allow a full discussion of the principles underlying these methods; the following brief sketch must suffice. In a crystal the molecules are arranged in a three-dimensional pattern, analogous to the two-dimensional pattern on a sheet of wallpaper or in a tightly-packed group of billiard balls on a table. Passing through the units of the pattern – i.e. the molecules or parts of them – it is possible to describe a large number of sets of parallel planes in various directions; these are known as net-planes. In just the same way, from the window of a train passing a regularly-planted orchard, long lanes can be seen between rows of trees in many different directions.

The structure of these three-dimensional molecular patterns in crystals can be investigated with the help of X-rays. X-rays exhibit wave properties just as light does, but the wavelengths are much shorter than in visible light, of the order of a ten-millionth of a millimetre (known as one Angstrom unit – 1Å for short). The distances between the atoms in molecules are of this order of magnitude too, and a consequence is that when X-rays pass through a crystal they are reflected from the various net-planes, which act towards the X-rays much as a mirror does to ordinary light. Each type of plane in the crystal produces its own characteristic set of X-ray reflections, and in a suitable apparatus this 'diffraction pattern' can be recorded on a photographic plate (Plate 2). From measurements of the angles at which these reflections occur we may deduce the distance between the planes which caused them, and by measuring

their intensities it is possible in simple cases to discover the arrangement of the molecules in the crystal, their distances apart, and their internal structure. Protein crystals are enormously more complicated than the most complicated crystal whose structure has been completely determined by means of X-rays, and often it is not possible to do more than deduce the distances between the reflecting planes, in other words the *periodicities* which characterize the structure – the distance between the trees, to revert to the orchard simile. In fibres the structure, though partly regular, is more disorderly than in a true crystal, with the result that the X-ray patterns contain only relatively few reflections, and those blurred and spread out. In such a case all we can do is calculate the periodicity in the structure corresponding to each reflection; in addition it is possible to say in which direction each periodicity lies, whether along or across the fibre axis, or at some definite angle to it. These periodicities must represent regular repetitions of some group of atoms in the fibre, and the task of the analyst is to correlate them with what he knows of the chemical structure of the fibre, and to draw up a model of the structure which would yield all the X-ray reflections observed.

It is a well-known fact that many keratin fibres, such as wool, can be made to stretch to about twice their natural length. Astbury and his collaborators made the fundamental discovery that the unstretched form and the stretched form, known respectively as α-keratin and β-keratin, give each their own characteristic X-ray pattern. Both contain a reflection corresponding to a fundamental periodicity (or in other words to a repeating unit in the molecular structure) along the axis of the fibre; but in α-keratin the repeat distance is 5.1 Å, while in β-keratin it is 3.34 Å. Many other reflections have been recorded in the patterns of the two forms of keratin, corresponding to much longer repeat distances. The differences between the two patterns leave no room for doubt that the α- and β- forms possess different structures, but the data are still not adequate for an incon-

trovertible *interpretation* of the patterns in terms of molecular structure, and the literature for the last ten years has been full of hypotheses and speculations of varying degrees of plausibility. The most widely accepted of these hypotheses is that advanced by Astbury, who has suggested that the structures of the two forms are as shown diagrammatically in Fig. 10. It will be seen that the stretching which takes place when α-keratin is converted into the β-form is accounted for in terms of an unfolding of the polypeptide chain; the side chains lie perpendicular to the plane of the paper in each case (the diagram does not give details of the polypeptide chain, which is shown as a straight line for β-keratin although in fact it still has the zigzag form shown in Fig. 9).

A further contribution made by Astbury was the discovery that myosin, the contractile protein of muscle, must resemble keratin in important respects since, under suitable conditions, it yields X-ray pictures of a very similar kind.

Another physical tool which has been used for studying

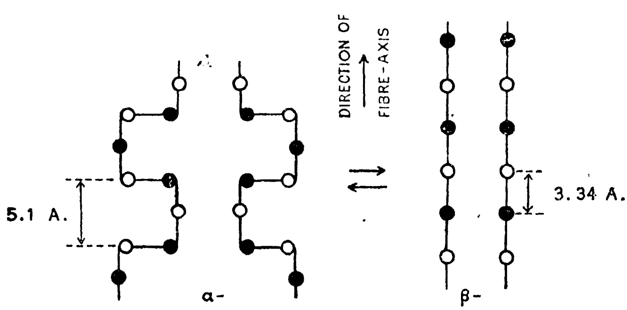


Fig. 10. – Astbury's model for the structures of α-keratin and β-keratin.

— represents the direction of the main chain.

O represents a side-chain pointing *up* from the plane of the diagram.

● represents a side-chain pointing *down* from the plane of the diagram. (By courtesy of *Nature*, after Astbury & Bell, **147**, 696 (1941)).

fibrous proteins is the electron microscope. This instrument has been described in an article by E. M. Crook in *Science News* 1, and also by V. E. Cosslett in *New Biology III*, so it is unnecessary to say more here than that by its use images of very small objects can be obtained on an extremely enlarged scale, the limits of resolution being as small as 50 Å or even less in favourable circumstances. The electron microscope has been used by the schools of F. O. Schmitt and R. W. G. Wyckoff in America and others to obtain photographs of many fibrous proteins; an example of such a photograph is shown in Plate 1 which is an electron micrograph of individual fibres of collagen, teased out from tendon. It will be seen that the fibres show transverse striations; this is a phenomenon often met with, and in this particular case the distance from one dark band to the next is about 640 Å. The significant thing about this distance is that the X-ray pattern of the same fibres contains a reflection corresponding to an identical repeat distance along the fibre axis. So it seems that the gap between microscopic vision and the submicroscopic vision of X-rays is beginning to be bridged; but it must be pointed out that the degree of resolution at present obtainable in electron micrographs is insufficient to provide evidence either for or against any particular theory of the detailed arrangement of the polypeptide chains.

The globular proteins. We have mentioned the use of the ultracentrifuge and other methods for determining the molecular weights of globular proteins. Several of these methods, including the ultracentrifuge, can also be used to get some idea of the shape of the molecules. The principle involved is analogous to that by virtue of which a piece of paper, released from the top of a building, flutters to the ground less quickly than would a similar one screwed up into a ball. In other words, the rate of sedimentation is a function of the shape as well as of the weight of the molecules. Similar effects of shape can be measured by other methods involving the motion of particles through the solution,

whether induced by electric fields, diffusion gradients, or other means. The results are not very precise and only give a general idea of the degree of asymmetry of the molecule; nevertheless they have shown that the term 'globular' is used with justification.

However, the principal contribution to our knowledge of globular protein structure is that initiated in the years immediately before the 1939-45 war by Bernal and his collaborators, in their highly important researches using the methods of X-ray crystallography. They first had to discover how to obtain adequate X-ray diffraction photographs from crystals of proteins, but once the difficult technique of handling these fragile crystals had been mastered it was found possible to obtain from them patterns containing a wealth of detail (a typical X-ray photograph from a protein crystal is shown in Plate 2). Crystals of the same protein always gave patterns identical in all respects; and the details of X-ray diffraction patterns are so sensitive to slight changes in the structure of the crystals from which they are derived that this constancy is one of the strongest pieces of evidence that globular proteins do indeed possess structures unvarying and characteristic down to the finest details.

Of the proteins first examined by Bernal and his team, horse haemoglobin has since yielded the most detailed information as a result of the long-continued and intensive studies of Perutz. Haemoglobin is a protein contained in the red corpuscles of mammalian blood; it is responsible for their colour, and its physiological function is to transport oxygen from the lungs to the tissues. Its property of reversible combination with oxygen gives it great intrinsic interest, but quite apart from this it lends itself particularly to the X-ray technique because it readily forms crystals of great perfection and considerable size.

Haemoglobin has a molecular weight of about 67,000 – relatively small as proteins go, but very large by comparison with any substance whose structure has so far been fully

determined by means of X-rays. One of the most complicated structures so far worked out fully is that of penicillin; this molecule contains about forty atoms, and the structure determination took several workers two or three years to complete, although much was already known about the structure from purely chemical reasoning. Haemoglobin contains about *ten thousand* atoms, so it is not surprising that the complete elucidation of its structure remains a task for the future. It is, however, possible to describe some of its main features on the basis of the studies so far made. The haemoglobin molecule (see Fig. 11) is cylindrical in shape, the base of the cylinder being a circle of radius 28Å and its height 34 Å. Inside it the matter is arranged in four parallel layers, each just under 9 Å thick, as shown in the Figure; the molecule might be compared with a pile of four coins.

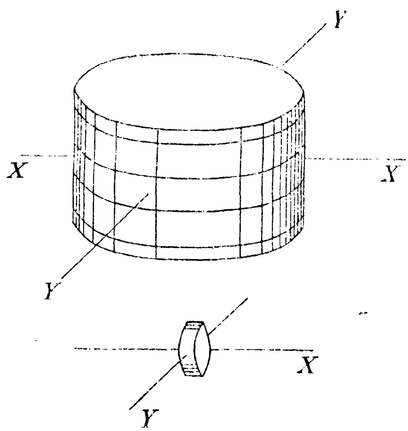


Fig. 11. – Diagrammatic model of the haemoglobin molecule. The small disk underneath represents a haem group drawn on the same scale and in its correct orientation with respect to the molecule. The four lines on the cylinder surface indicate the position of the four layers. (Redrawn from J. Boyes-Watson, E. Davidson and M. F. Perutz, Proc. Roy. Soc. *A*, **191**, 83 (1947).)

It has been known for a long time that the point of attachment of oxygen to the haemoglobin molecule is a flat group of atoms known as the haem group. This group has an iron atom at its centre and its chemical structure is well known, since it can easily be separated intact from the protein and subjected to analysis by ordinary methods (such a non-protein moiety forming the principal active group in a protein is known as a *prosthetic group*, and a protein containing it, a *conjugated protein*). Haemoglobin contains four haem groups in each molecule, and each of these can attach one oxygen molecule. Study of the crystals has shown that the haem groups must be parallel to one another and perpendicular to the main layer structure; their relative positions are still undetermined, but their orientation is indicated in the Figure by the small disk underneath the haemoglobin cylinder.

It has recently become possible, as the result of extremely lengthy calculation, to say something about the internal structure of the molecule. It seems that each of the four main layers consists of a disk of parallel polypeptide chains packed together like the cigarettes in a flat cigarette case. These chains are parallel to the direction marked X-X in the diagram, in other words perpendicular to the haem groups; and it seems very probable that the way they are folded is the same as in α-keratin. This is as far as the analysis goes at the present time. It will be seen that although nothing like a complete determination of structure has yet been achieved, we are beginning to have a good idea of the general layout of this particular protein molecule; and the resemblance between the folding of its chains and the type of folding in α-keratin confirms earlier suspicions that there may be a close relationship between the structures of the fibrous and the globular proteins.

The present author has recently made a study of crystalline myoglobin, a protein similar in appearance and function to haemoglobin, except that it is fixed permanently in muscle tissue where it appears to act as an intermediary

between the haemoglobin in the blood stream and the oxidation systems of the muscle cell, oxygen molecules being passed from haemoglobin to myoglobin, and thence transferred to the muscle enzymes. Its molecular weight is one quarter of that of haemoglobin, and the molecule contains only one haem group instead of four. The preliminary X-ray results appear to support the tempting hypothesis that myoglobin is similar to just one of the four layers of haemoglobin – a single flat pack of parallel polypeptide chains in the α-keratin configuration, only one chain deep with the haem group again perpendicular to the plane of the disk; in other words, one penny to haemoglobin's fourpence.

A number of other crystalline globular proteins have been studied in more or less detail by X-ray methods – particularly insulin, by Dorothy Crowfoot – but none of them have revealed the secrets of their structure to anything like the same extent as has haemoglobin.

We shall conclude this brief account of researches on the structure of globular proteins with the results of electron microscope studies. The resolution obtainable with this instrument is insufficient to show up internal details of the kind we have just discussed, and it is even inadequate to elucidate the external shape of globular protein molecules except in the broadest terms; generally the individual molecules show up merely as formless lumps. Perhaps the finest pictures published till now are those by Polson and Wyckoff of haemocyanin, a blood pigment found in invertebrates; its molecule is so large that much more detail than usual can be seen (see Plate 3). Careful examination of the photographs shows that each molecule (of molecular weight about 6,800,000, i.e. about 100 times that of haemoglobin) consists of rod-like sub-units stacked together in bundles of four. The sub-units are about three times as long as they are thick and the composite particle is cube-shaped. This

demonstration that the molecule consists of sub-units is particularly interesting in view of the fact, known for some years, that haemocyanin readily dissociates in solution under favourable circumstances to particles of smaller molecular weight.

Viruses and the self-duplication of proteins. Electron micrographs have been made of even larger protein molecules, the viruses. These substances are responsible for many diseases of plants and animals, and chemical analysis shows that they are proteins. We are accustomed to attribute disease to small living organisms, and at first sight the idea that it should be caused by large molecules is a strange one; nevertheless many viruses show all the characteristics of pure chemical individuals. They can be purified by the methods of chemistry, and many of them form crystals as perfect and regular as those of simple inorganic substances, and yielding X-ray diffraction patterns containing thousands of reflections.

Photographs of the faces of virus crystals have been taken with the electron microscope, and they show the individual virus molecules arrayed in an orderly lattice; often their shape can be seen too. An example is given in Plate 4 which shows crystals of the plant virus responsible for Southern Bean Mosaic disease.

For many years there has been a controversy as to whether viruses are properly to be regarded as living things. Certainly they are not mere poisons, for in suitable environments (the cells of their hosts) they multiply like bacteria; but it is hard to conceive a living organism which can crystallize. Perhaps to-day the controversy has lost some of its interest as the boundary between living and non-living has become more blurred; but it remains a most remarkable phenomenon, that bodies which display all the properties of single protein molecules, albeit very large ones, should be endowed with the power of self-duplication.

Indeed the viruses are not the only case. Every living cell contains in its nucleus a number of chromosomes, long

thread-like bodies which bear along their length the genes which are responsible for the hereditary make-up of the cell. During cell division the chromosomes reduplicate themselves by dividing longitudinally. Now the chromosomes consist partly of proteins; indeed it is very probable that the genes themselves are proteins, since it is thought unlikely that the chemical structure of nucleic acids, which are the other main constituent of chromosomes, is capable of enough variation and specificity to account for the manifold properties of the genes. A point of cardinal importance in genetics is the persistence of hereditary characters through many generations and many cell divisions; and since these characters are caused by the genes, we must suppose that they can reproduce themselves quite unchanged from generation to generation. Alterations in the genes, known as mutations, certainly do occur; but statistically speaking they are rare events – the exception rather than the rule. So here too we have a case of proteins reproducing their kind with the greatest exactness. How it is done is one more of the unsolved problems of protein chemistry – one of the problems which we cannot hope to solve until we know more of the structure of the proteins themselves.

VI. The relation between fibrous and globular proteins

In conclusion we return to the question put by Astbury in 1936. The scheme of things which we have sketched out in the last few sections agrees essentially with the first of his alternatives; in other words, fibrous proteins seem to consist of more or less orderly bundles of polypeptide chains arranged roughly parallel and extended linearly, while globular proteins are aggregates of polypeptide chains folded or coiled together into a nearly spherical or globular shape. But during the last year or two a number of new results have been announced which seem to show that things are not so simple after all.

One of the most remarkable of the new findings is the discovery that insulin can assume a fibrous form. Insulin has always been thought of as a typical globular protein; it is soluble in water and of fairly low molecular weight, and measurements of its properties in solution show that it indubitably possesses a shape not far removed from the spherical. However Waugh has recently shown that, under suitable conditions, heat treatment of a simple kind causes it to aggregate into fibres which are precipitated from the solution. So far this sounds like the irreversible denaturation undergone by nearly all proteins when their solutions are heated – another case of hard-boiling the egg. But in fact the phenomenon is quite a different one, for the aggregation is reversible, and after disaggregation the protein regains nearly all of its original physiological activity; so we are not dealing with a process involving merely random disorientation of the original specific configuration of the polypeptide chains. The key was provided by the electron microscope, which shows that these fibres are formed by linear aggregation of roughly spherical particles, so here we seem to have an undoubted case of a fibre with a 'string of beads' structure (though so far there is no evidence that the individual bead is the same as a globular insulin molecule).

Again, in Schmitt's laboratory in America electron microscope pictures have been taken of single fibrils of invertebrate muscle, with such high resolution that the banded structure familiar in earlier electron micrographs of many types of fibre (see e.g. Plate 1) breaks up into transverse rows of spots whose diameters must be of the order of 100 Å. One of these pictures is shown in Plate 5. More recent pictures with still higher magnifications show that these spots are indeed globular particles.

These results were obtained with whole muscle fibres. It is also possible to extract various component proteins from intact muscle, and recent investigations of such extracts threaten to overturn many of our earlier ideas about muscle structure and behaviour. To do justice to them would

demand a separate article; what is relevant to our immediate argument is that one of these proteins, named actin by Szent Györgyi and his school in Budapest who discovered it, is capable of existing in two interconvertible forms, one globular and one fibrous. Furthermore the fibrous form is derived from the globular by linear aggregation in a way very reminiscent of insulin. Yet another muscle protein, discovered by Bailey and known as tropomyosin, has now been shown to exist in both globular and fibrous forms.

A final piece of evidence comes from the Australian workers Farrant, Rees, and Mercer, who claim that keratin also is a string of beads (as briefly reported in *Science News* 5, p. 61). Their electron micrographs of wool fibres show two components, small fibrils and an amorphous matrix in which the fibrils are embedded. The matrix consists of spherical particles of about 100 Å diameter, while the fibrils are formed from several smaller 'protofibrils' twisted together ropewise; the protofibrils – and this is the significant observation – seem to consist of globular particles (of about 110 Å diameter) strung together. One of the electron micrographs is given in Plate 6. Certain criticisms of a technical nature have been levelled against these results; but they certainly accord well with the other cases we have mentioned, and it is to be hoped that the structure of keratin, the fibrous protein *par excellence*, will be examined in more detail.

So far these are isolated results and more research is needed before we shall be entitled to make a radical revision of our ideas about the structure of proteins. But provisionally we may perhaps think in terms of three levels of structural complexity. First we have the individual polypeptide chains; second, folded arrangements of chains into globular particles which may have an independent existence as the familiar 'globular proteins'; and third, linear aggregates of globular particles into 'strings of beads' or fibrous proteins. This picture of protein structures is tentative and

unproved, possibly even quite wide of the truth; but it seems appropriate to conclude a survey of this field of research, which is in so active a state of transition and development, with a question mark.

Acknowledgements for plates 1–5 of the inset, illustrating this article, are due to the following:

PLATE 1: F. O. Schmitt, J. Am. Leather Chemists Assoc. **39**, 430 (1944).

PLATE 3: Polson, A. and Wyckoff, R. W. G., *Nature*, **160**, 153 (1947).

PLATE 4: Price, W. C. and Wyckoff, R. W. G., *Nature*, **157**, 764 (1946).

PLATE 5: C. E. Hall, M. A. Jakus and F. O. Schmitt, *J. App. Phys.* **16**, 459 (1945). Courtesy of the *Journal of Applied Physics.*

PLATE 6: Farrant, J. L., Rees, A. L. G., and Mercer, E. H., *Nature*, **159**, 535 (1947). Fig. 2. Courtesy of the Council for Scientific and Industrial Research, Melbourne.

About Our Contributors

A. R. C. Butson was born in 1922, and educated at St. John's College, Cambridge, and then at University College Hospital, London. After qualification he spent one year as a doctor at his hospital and then became medical officer to the Falkland Islands Dependencies Survey, 1946-8. Albert Medal, 1948. At present assistant lecturer at the Anatomy Department, University College, London.

K. G. Collier was born in 1910 and educated at Aldenham School and Cambridge. He is now a Science Master at Lancing College, and a contributor to various educational journals. His experience, particularly as a chemist in an Ordnance Factory during the war, has led him to regard the relation of science to civilization as one of the burning problems of the century, and to consider that the key to it lies with the social sciences. He lectures on these subjects for the Workers' Educational Association and has recently written a book on them, *The Science of Humanity*. He is married and has two sons.

T. A. Lloyd Davies is Chief Medical Officer to Boots Pure Drug Company Limited, Nottingham. At St. Thomas' Hospital he won the Mead Medal and Toller Prize. He is an honorary member of the Cercle d'Études des Chefs de Services Médico-Sociaux d'Industrie, and his publications include *The Practice of Industrial Medicine* (Churchill).

P. D'Arcy Hart was educated at Cambridge and University College Hospital Medical School. After qualifying he held various clinical and research appointments at University College Hospital, finally being appointed Assistant Physician to the hospital. In 1937 he joined the Scientific Staff of the Medical Research Council for full-time research work on chest diseases. He is a member of the Expert Committee on Tuberculosis of the World Health Organization and of the Standing Advisory Committee on Tuberculosis of the Ministry of Health, and Secretary of the Medical Research Council's Streptomycin in Tuberculosis Trials Committee.

Lawrence E. Hudson took the Natural Science Tripos at Cambridge in Physics. Joined the R.N.V.R. as a Radar Officer, 1941. On demobilization entered G.E.C. Research Laboratories, first as Librarian and finally as a member of a group working on agricultural applications of electricity.

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Oliver Graham Sutton is Bashforth Professor of Mathematical Physics at the Military College of Science, Shrivenham, Wilts. He left university teaching to join the Meteorological Office in 1928, for research work on turbulence in the lower atmosphere. During the war he was successively Superintendent of Research at the Chemical Warfare Experimental Station, Superintendent at the Tank Armament Research Establishment, Chief Superintendent of the Radar Research and Development Establishment, Malvern, Worcs. He is married and has two sons.

G. P. West is a veterinary surgeon and an associate member of the Guild of Agricultural Journalists. After six years in the Army and 18 months in the Foreign Office, he is now on the staff of the National Veterinary Medical Association.

GLOSSARY

AZIMUTH is an angle used in describing accurately the position of an astronomical body in relation to the meridian or North-South axis of the earth, for convenience imagined as prolonged indefinitely into space. Strictly, it is the angle measured at the zenith, i.e. vertically overhead, between the meridian and the axis of an imaginary vertical circle which includes the star, etc., and the zenith, on its circumference.

BROWNIAN MOTION is the erratic, zig-zag, movement made by small (microscopic) particles such as pollen grains when floating in a fluid as a suspension. It is caused by the moving molecules of the fluid striking the particle haphazardly, first on this side, then on that, and making it oscillate visibly. Named after its discoverer, the botanist Brown.

CRYSTALLITE: a microscopic grain of a metal or alloy, visible as a distinct entity under the microscope when a metal sheet is carefully examined, and composed of several metal crystals.

DECLINATION, MAGNETIC, is the angle between the direction of the magnetic north, indicated by a compass needle, and the true or geographic north.

DÖPPLER EFFECT: Any form of energy coming in rhythmic pulses, for instance light waves or sound waves, comes towards a stationary observer at a definite frequency of so many a second, which is recognised characteristically by the appropriate sense-organ as a specific colour or note. Thus the musical note *middle C* when sounded strikes the ear drum as a series of little puffs of air arriving at the rate of 256 per second; if the same little puffs arrived at a different frequency, for instance twice as often (512 per sec.), the ear would hear a totally different note, in this particular case *top C*. Similarly with light: what the brain through the agency of the eye interprets as a particular colour is physically the frequency with which little packets of light energy are striking the retina.

But suppose the observer is not stationary, but moving fast. If he moves quickly *towards* the source of light or sound, he receives more impulses of energy in a single second than he would have done if he had stayed still (because he has gone to meet the energy, and received pulses which would otherwise still have had some way to go to reach him) and so he thinks the note is higher pitched, or the light bluer than he otherwise would. On the other hand if he is moving *away*, he receives fewer pulses or

waves of energy per second than the source is emitting, and so he has the impression that the note is lower or the light redder than it is.

The observer can use this shift in frequency which he measures to calculate his own velocity; the shift is called the Döppler effect.

MEAN FREE PATH: The molecules in a liquid or gas are in incessant motion, according to the kinetic theory, and the mean free path is the distance one may travel before it collides with another, or the distance a moving atom or molecule can move into a solid before suffering a collision.

The actual value, which is of course a statistical mean in any given case, depends on the precise condition of the substance. It will obviously be much greater, for instance, in a rarefied gas, with few molecules per cubic centimetre, than in a compressed gas about to liquefy.

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